BACHELOR THESIS & COLLOQUIUM – ME141501

RISK ASSESSMENT OF SHIP COLLISION AND GROUNDING IN SURABAYA WEST ACCESS CHANNEL DUE TO THE EXISTENCE OF SHIPWRECKS

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DOUBLE DEGREE PROGRAM
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APPROVAL FORM

RISK ASSESSMENT OF SHIP COLLISION AND GROUNDING IN SURABAYA WEST ACCESS CHANNEL DUE TO THE EXISTENCE OF SHIPWRECKS

BACHELOR THESIS

Submitted to Comply One of the Requirements to Obtain a Bachelor Engineering Degree
on
Laboratory of Reliability, Availability, Management, and Safety (RAMS)
Bachelor Program Department of Marine Engineering
Faculty of Marine Technology
Sepuluh Nopember Institute of Technology

Prepared by:
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RISK ASSESSMENT OF SHIP COLLISION AND GROUNDING IN SURABAYA WEST ACCESS CHANNEL DUE TO THE EXISTENCE OF SHIPWRECKS

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ABSTRACT

Surabaya West Access Channel (SWAC) is a shipping lane in the Madura Strait. This shipping lane has a very crowded ship traffic. In 2016, there are 62,091 ships sailing around SWAC. The number of these ships caused a lot of ship accidents, such as ship collisions and ship grounding. The shipwrecks caused by the ship's accident caused a new problem for ship traffic. These shipwreck will eventually cause the collision of ship and ship grounding. According to the KPLP (*Kesatuan Penjaga Laut dan Pantai*) there are 22 shipwrecks in SWAC. The frequencies of ship collision and ship grounding due to shipwrecks will be analyzed with IWRAP software and manual calculations. The results of each head-on, overtaking, and crossing collision are $6.99 \cdot 10^{-3}$; $1.02 \cdot 10^{-3}$; $7,768 \cdot 10^{-3}$ for manual calculation, then $7.07 \cdot 10^{-3}$; $9.04 \cdot 10^{-4}$; $7,789 \cdot 10^{-3}$ for IWRAP analysis. The frequencies of ship grounding of the ship for each powered grounding and drifting grounding are $6.1 \cdot 10^{-3}$; $1.27 \cdot 10^{-4}$ for manual calculation analysis, then $7,764 \cdot 10^{-3}$; $1,196 \cdot 10^{-4}$ for IWRAP analysis. The ship collision and ship grounding caused damage to the ship's structure. Ansys software is used to analyze this damage. The output of the analysis is the total deformation and equivalent stress. Total deformation is the total displacement of structures for all axes. Meanwhile, the equivalent stress is the total stress that hit the collision area. The maximum of total deformation of any ship collision and ship grounding are 5×10^{-2} m and 5.4×10^{-2} m. Therefore, the maximum of equivalent stress for each ship collision and ship grounding are 1.64×10^{9} Pa and 6.78×10^{9} Pa. The consequences of ship collision and ship grounding produce low deformation and high equivalent stress. Incidentally, ship accidents cause huge losses to the structure and safety of ships.

Keywords: Ship Accidents, Ship Collision, Ship Grounding, Shipwreck, Damage Analysis, Surabaya West Access Channel.

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PREFACE

Grateful to the God because of His grace, the author can finish this bachelor thesis with title "RISK ASSESSMENT OF SHIP COLLISION AND GROUNDING IN SURABAYA WEST ACCESS CHANNEL DUE TO THE EXISTENCE OF SHIPWRECKS
" in order to fulfill the requirement of obtaining a Bachelor Engineering Degree on Department of Marine Engineering, Faculty of Marine Technology, Sepuluh Nopember Institute of Technology.

Along the process of writing this bachelor thesis, author want to give thank you to the all people who helped and support, among others:

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Author hoping this bachelor thesis can help those in need for the better research and if there any comments from the reader, author is open for it.

Surabaya, July 2018

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CHAPTER 1
INTRODUCTION

1.1 Background

Surabaya West Access Channel (SWAC) is a shipping route in the Madura Strait. This shipping lane has a busy ship traffic. Currently, SWAC has a width of 150 m, with a depth of 8.5 m, and a length of 24.2 NM. According to Annual report of PT. Pelindo in 2016, the total number of ships sailing in SWAC is 62,091 units. The total number of ships sailing in SWAC can be analyzed using data from AIS. AIS data itself has information about the location of the ship, the direction of motion, speed, as well as the length and type of the vessel. Therefore, areas in SWAC that have a large number of ship spans can be known. With the high number of ship traffic in SWAC can lead to high probability of ship accidents.

The occurrence of a shipwreck in SWAC caused a new problem, the shipwreck on the seafloor caused by previous ship accidents. According to the Sea and Coast Guard Unity (KPLP) there are 22 shipwrecks located on the seabed SWAC. These shipwrecks include the Tanto Hari Ship. Some of the wrecks are relics of the Dutch East Indies and some are from Indonesia. With this large number of shipwrecks, it is feared will be a source of new problems for ship traffic in SWAC in the future.

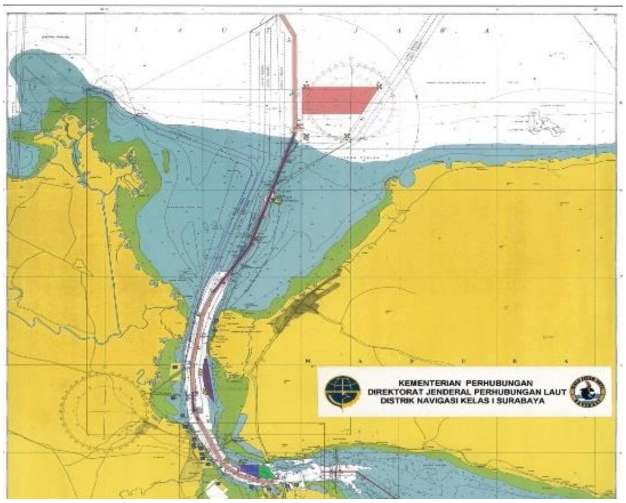

Figure 1.1 Surabaya West Access Channel
Source: (PT. APBS)

These shipwrecks indirectly causes silting the depth of the SWAC water area. Therefore, causing the risk of collision and the ship grounding to become larger. For example on September 24 2016, the sinking of KLM Berkat Mulia ship due to shipwreck Tanto Hari. The same thing experienced by KLM Anugrah Indah who sank due to hit the ship Tanto Hari, and several other accidents caused by shipwrecks around SWAC waters.

Risk assessment should be conducted on ship accidents caused by shipwrecks in SWAC waters. This risk assessment aims to calculate the ship's grounding frequency caused by shipwrecks and ship foundations and how are their consequences. Frequencies will be analyzed using IWRAP software and manual calculations, therefore valid results will be obtained. Then the consequences are analyzed using Finite Element Analysis (FEA). Therefore, it can be calculated the energy released or absorbed from a ship accident and can be determined how the damage arising from the crash of the vessel.

IWRAP is a software or application that can be used to model the risk assessment of maritime issues. IWRAP can be used to estimate the frequency of ship collisions and ship grounding on a particular shipping path. This estimate is based on traffic volume, ship route, and ocean depth. Meanwhile, the consequences of ship and ground collision analysis will use software based on Finite Element Analysis (FEA), for example ANSYS, ABAQUS, etc. Finite Element Analysis (FEA) is a method that results in a solution approach and its accuracy depends on many factors including the number of mesh. On the analysis of material damage such as plate breakage, the number of mesh is an important factor for modeling material failure.

1.2 Statement of Problems

According to description above the statements of problems of this bachelor thesis are:

1. How large is the frequency of ship collisions and grounding due to shipwrecks at some point around the SWAC?
2. What are the consequences due to the occurrences of ship collision and grounding caused by the shipwreck around SWAC?

1.3 Objectives

The objectives of this bachelor thesis are:

1. Calculating the frequency of ship collision and grounding caused by shipwrecks around the SWAC.
2. Calculating the consequences of ship collisions and grounding caused by shipwrecks around the SWAC.

1.4 Research Limitations

This research will conduct around the SWAC. Risk assessment is conducted on the most vulnerable areas of ship collision and grounding due to shipwrecks. The area is designated as an area with heavy vessel traffic and the presence of shipwrecks. In this case, IWRAP will be used to simulate ship accidents and ANSYS software will be used for accident modeling.

1.5 Benefits

The several benefits of this bachelor thesis are:

1. Providing information about the hazard of the ship collisions and grounding as a result of shipwrecks around the SWAC waterway.
2. Providing information about the value of frequencies of ship collisions and ship grounding around SWAC

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CHAPTER 2
LITERATURE STUDY

In this bachelor thesis, ship collision and grounding will be modelling to IWRAP software. Then the consequences of the accidents will be modeled using FEA in ANSYS software. There are 3 scenarios of ship collision and 2 scenarios of ship grounding in IWRAP software. These scenarios are Head-on Collision, Overtaking Collision, and Crossing Scenario. However, grounding scenarios are powered grounding and drifting grounding.

FEA is a numerical engineering method to analyze complex engineering problems. This method is one of the best methods to solving several practical problems efficiently. Nowaday, many computer programs have been developed to analyze FEA, for example: Algor, Abaqus, Ansys, NISA, SAP2000, COSMOS/M, and etc. ANSYS is used to model FEA in this bachelor thesis.

There are several advantages for using FEA computer programs:

1. The FEA programs are comparatively cheap and short
2. Programs can be used in low specifications computer
3. Programs can solve the problems quickly and low cost

2.1 Risk Model

Risk model can be explained as a potential number of grounding or ship collision which is determined as the absence of ship maneuvers performed. The potential number of ship accidents is due to a) it is assumed that the geometric distribution of the shipping traffic has exceeded the pathway's capacity and b) it is assumed that the navigation of the vessel is in poor condition / damage, resulting in the ship sailing outside the waterway.

This potential number will be used to determine the actual number of an event (accident). Causation probability is used in this calculation. Causation probability itself is defined as a thinning probability that estimates the state at the time of blind navigation. Therefore, the causation probability must be determined conditionally based on the accident scenario.

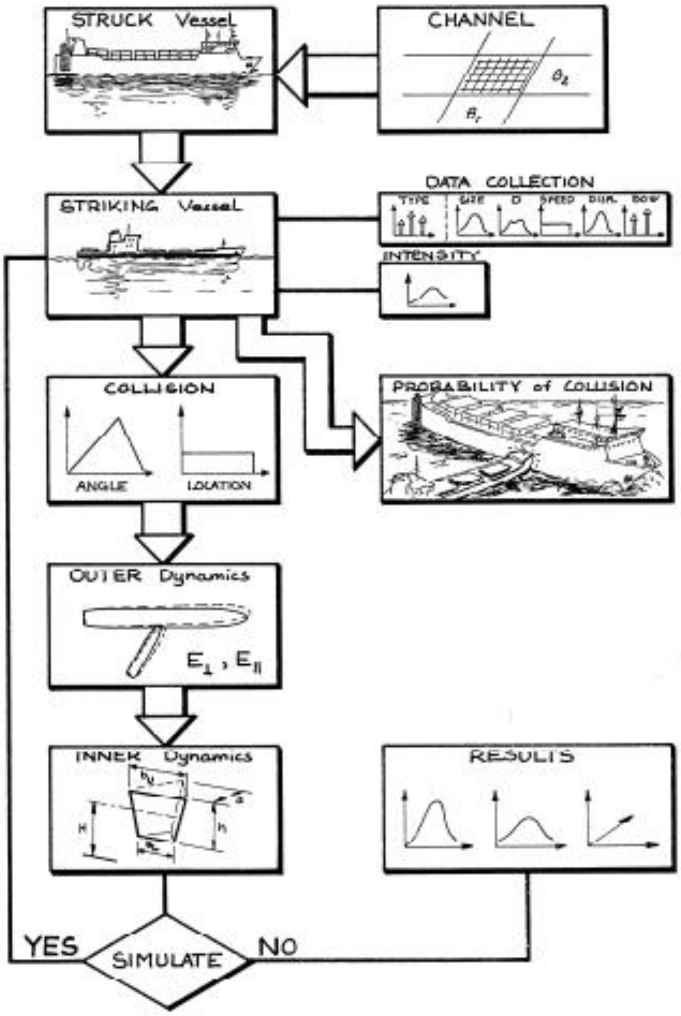

Figure 2.1 Procedure of Probability Prediction and Spatial Distribution of Ship Collision
Source: *(Fris-Hensen, 2007)*

Figure 2.1 illustrates the steps for modeling the ship's impact. Modeling of ship collision at this time using method like figure 2.1, similarly with ship grounding too. The first step is to determine the navigation area of the simulation including the ship's traffic condition along the waterway, and mapping the seabed area. Then, determining ships that go through the waterway and the seabed conditions, so as calculating the probability of the occurrence of ship grounding and collision. Striking seabed and ship areas were also determined to analyze the damage statistics.

In this bachelor thesis, the shipwreck is the main focus. Because the presence of shipwrecks in the SWAC area become obstacles on the ship, therefore causing the occurrence of ship accidents (collision or grounding). Therefore, the points where the wreck is located are vulnerable to the occurrence of ship accidents.

2.2 Definition of Ship Collision

Ship Collision is defined as the physical impact of that caused by two or more ships resulting in an accident. Collisions can also occur between ship and stable objects, such as platforms, docks, even wrecked shipwrecks as occurs in SWAC areas.

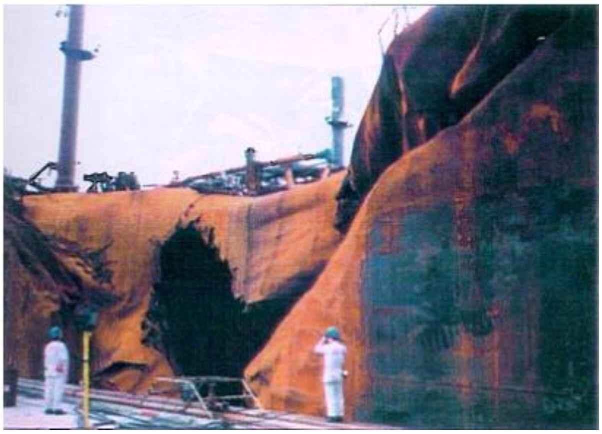

Figure 2.2 Damage Caused by Collision between 100,000 dwt Tankers Crashed by 22,600 dwt Container Ship in 1992
Source: (Zhang, 1999)

2.3 Definition of Ship Grounding

Ship grounding is the impact of ships that ride on the seabed and sides. Due to the large number of shipwrecks in SWAC waters, this can result in the occurrence of ship aground due to siltation by the presence of this shipwreck. The ship grounding can cause the bottom of the ship's double bottom to tear. So it is necessary to mitigate the case.

Figure 2.3 The Grounding of 147,000 dwt Tanker Ship in 1996
Source: (Zhang, 1999)

2.4 Frequency of Collision

The first step in calculating the frequency of collision and grounding is to determine the number of N_G candidates that will be multiplied by the Pc causation factor. Thus, the formula to calculate the frequency of the collision and grounding is.

$\boldsymbol{\lambda}_{\mathbf{Col}}$ = Pc x Ng, λ_{Gmd} for grounding 2.1

Collision is divided into 2, there are:

- Collision occur on the same route, e.g. overtaking and head-on collisions, etc.
- Collision occur on two routes and crash into each other

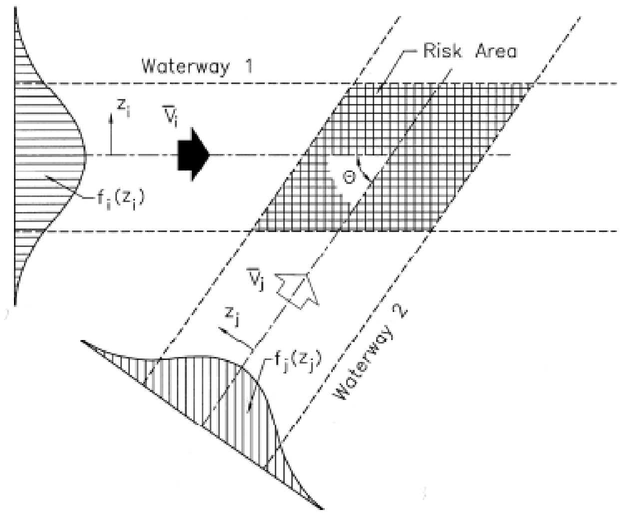

Figure 2.4 A Crossing Waterway can Cause a Ship Collision
Source: *(Fris-Hensen, 2007)*

2.4.1 Head-on and overtaking collisions

These types of collision depends on:

Lw	: The length of the segment
Q_i *and* Q_j	: Traffic composition in each direction
V_i *and* V_j	: Speed of vessels
$f_i(y_1)$*and* $f_{y_j}(y_j)$	: Probability distribution of ship traffic

In head-on collision, the number of N_G can be calculated with:

$$N_G^{head-on} = Lw \sum P_{Gi.j}^{head-on} \frac{V_{ij}}{V_i V_j}\left(Q_i Q_j\right) \qquad 2.2$$

Where, $V_{ij} = V_i + V_j$ is relative speed between vessels and P_G is probability that two ships will collide in a head-on collision. P_G is equal to:

$$P_{Gi.j}^{head-on} = \phi\left(\frac{\bar{B}_{ij}+\mu_{ij}}{\sigma_{ij}}\right) - \phi\left(-\frac{\bar{B}_{ij}+\mu_{ij}}{\sigma_{ij}}\right) \qquad 2.3$$

Where:

Φ : Standard normal distribution function

μ_{ij} : Average of sailing distance of two vessels

$$\mu_{ij} = \mu_i + \mu_j \qquad 2.4$$

σ_{ij} : Standard deviation of joint distribution,

$$\sigma_{ij} = \sqrt{\sigma_i{}^2 + \sigma_j{}^2} \qquad 2.5$$

B_{ij} : Average width of vessels

$$Bij = \left(\frac{Bi + Bj}{2}\right)$$

The overtaking collision also can be analyzed with the equation no 2 and 3. Thus, ship candidates for overtaking collision are:

$$N_G^{Overtaking} = Lw \sum P_{Gi.j}^{overtaking} \frac{V_{ij}}{V_i V_j} \left(Q_i Q_j\right) \qquad 2.6$$

Where,

$$P_{Gi.j}^{head-on} = \phi\left(\frac{\bar{B}_{ij}+\mu_{ij}}{\sigma_{ij}}\right) - \phi\left(-\frac{\bar{B}_{ij}+\mu_{ij}}{\sigma_{ij}}\right) \qquad 2.7\text{and}$$

$$\mu_{ij} = \mu_i - \mu_j \qquad 2.8$$

2.4.2 Crossing Collision

The number of candidates in crossing collision can be calculated using formula:

$$N_G^{crossing} = \sum_{i.j} \frac{Q_i Q_j}{V_i V_j} D_{ij} V_{ij} \frac{1}{\sin\theta} \qquad \text{for } 10^o < |\theta| < 170^o \qquad 2.9$$

Where $V_{ij} = \sqrt{(V_i)^2 + (V_j)^2 - 2V_i V_j cos\theta}$ is the relative speed of vessesls, and $D_{i.j}$ is diameter of apparent collision. $D_{i.j}$ is equals to:

$$D_{ij} = \frac{L_i V_j + L_j V_i}{V_{ij}} + B_j \left\{1 - \left(\sin\theta \frac{V_i}{V_{ij}}\right)^2\right\}^{1/2} + \left\{B_i 1 - \left(\sin\theta \frac{V_i}{V_{ij}}\right)^2\right\}^{1/2} \qquad 2.10$$

Where, B_i is width of ship i and L_i is length of ship.

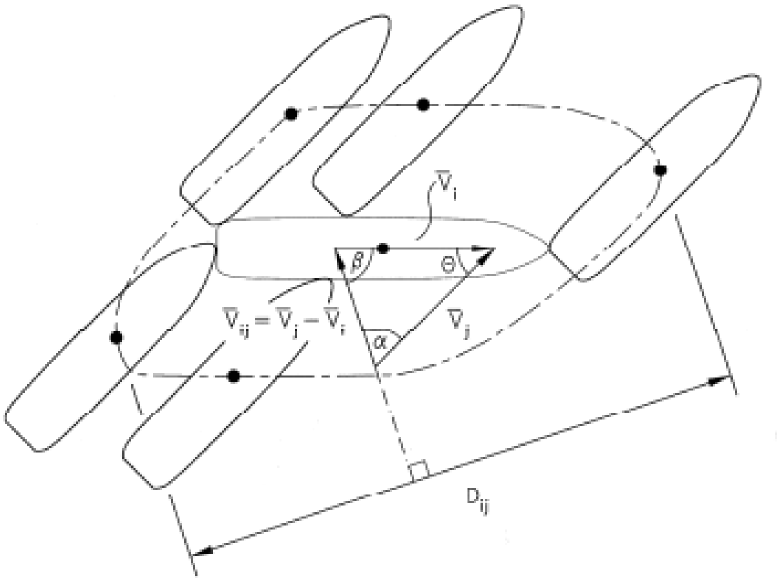

Figure 2.5 Definition of Dij
Source: (Fris-Hensen, 2007)

2.5 Probability of Grounding

Practically, there are 4 types of categories of ship grounding (Pederson, 1995). These 4 categories including:

1. Grounding on a ship that sails according to the existing route at normal speed. This incident is usually caused by human error and unexpected problems that occur in the ship, such as damage to the propulsion system and ship's movement system.
2. Failure of ships to avoid obstacles or certain objects that may cause the ship grounding
3. The ship is late to change the direction of motion so that eventually due to grounding or crashing something
4. Any other form of categories that may cause the ship grounding, such as total failure of the propulsion system.

From the four categories above, categories 1 and 2 are the categories that often cause the ship grounding. The vessels in categories 1 and 2 are sailing on the appropriate route, and are distributed on a route with probability density function (pdf) $f_i(z)$, where index i represents ship class and z means transverse coordinate. While f_i is the number of candidates from grounding can be calculated as an integral of f_i with a z_{min} to z_{max} limit of obstacles. Many ships will be hard to get past obstacles because they are not doing the right course in avoiding obstacles. Causation probability Pc will be caused by human error and technical failure. Other grounding can be caused by propulsion damage (rudder stuck).

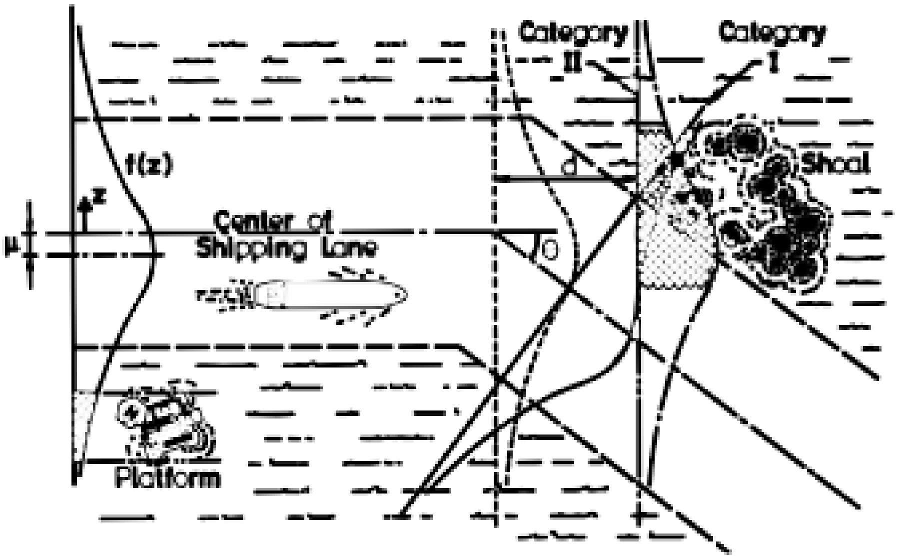

Figure 2.6 Illustration of Grounding Modelling with Fixed Objects
Source: (Fris-Hensen, 2007)

Grounding is divided into 2 scenario, there are:

2.5.1 Powered Grounding

In powered grounding, we can be calculated the value of expected number of ship grounding accidents from category 1 and category 2 using these formula:

$$N_I = \sum_{Ship\ class,i} P_{c,i} Q_i \int_{z_{min}}^{z_{max}} f_i(z)dz \qquad 2.11$$

Where,

i	: Index for ship class, categorized after vessel type and dead weight or length
$f_i(z)$	: Probability density function for the ship traffic
N_I	: Expected number of category I grounding events per year
$P_{c,i}$	: Causation probability, i.e. ratio between ships grounding and ships on a grounding course
Q_i	: Number of ships
z	: Coordinate in the direction perpendicular to the route
z_{max}, z_{min}	: Transverse coordinate for an obstacle

Assume position checking can be described as Poisson process. Exp (-d / a) represents the probability of the navigator not checking the position from the bend to the obstacle. Average distance of checking position λ, approximately 3 minutes. Where exp (-d / a) becomes a function of the velocity of the vessel, ai = λV.

With the above formula, the number of expectation of grounding accidents be a function of the distribution of ship traffic, topology of the seabed, ship routes, etc. Causation factor is usually given for grounding of Pc = 2.10-4. The expected annual amount of powered grounding can be calculated with, Ng = $N_I + N_{II}$. The probability of grounding in a year is: P [Grounding] = 1 - exp (-Ng)

2.5.2 Drifting Grounding

Drifting grounding is caused by 2 main causes, namely rudder stuck and main engine blackout. Events caused by rudder stuck will not be discussed, black out has a big role to grounding. In one year, the ship experienced 1 blackout, usually the blackout frequency in one year between 0.1 - 2 blackout. In research conducted frequency of blackout is as follows:

Table 2.1 Frequency of blackout

Vessel Type	Annual frequency	Hourly frequency
Passenger/Ro-Ro	0.1 y^{-1}	$1.15 \cdot 10^{-5} h^{-1}$
Other vessels	0.75 y^{-1}	$8.56 \cdot 10^{-5} h^{-1}$

Blackout can caused by main engine failure, fuel, or failure in electrical system. It can dangerous because the location of blackout occurs. Wind speed and direction can be cause drifting. The ship can drift side ways and will drift in same direction of wind.

Probability of blackout along $L_{segment}$ is:

$$(L_{segment}) = 1 - exp\left(-\lambda_{blackout} \frac{L_{segment}}{v_{vessel}}\right) \quad 2.12$$

Where, $-\lambda_{blackout}$is frequency of blackout and v_{vessel} is service speed of ships. $N_{grounding}^{drift}$ can be calculated:

$$N_{grounding}^{drift} = N_{ship} \int_{\psi=0}^{360} P_{wind}(\psi) \sum_{All\ segments} P_{blackout}(L_{segment})$$

$$\int_{x=0}^{L_{segment}} \int_{All\ v_{drift}} P_{no\ repair}\left(t_{ground}\middle|Z\right) P_{no\ anchoring}(t_{ground|Z}) f(v_{drift}) dv_{drift} dx d\psi \quad 2.13$$

Where, the repair time is determined as:

$$P_{repair}(t) = 1 - \exp(-at^b) \text{ and} \quad 2.14$$

$$P_{no\ repair}(t) = \exp(-at^b) \quad 2.15$$

Known scale parameter a=1,05 and shape parameter b=0,9. Mean value of 1 hour and standard deviation 1.13 hour.

$t_{ground} = d_{ground}/v_{drift}$, which v_{drift} is drifting speed and d_{ground} is distance from leg segment to ground/obstacle.

2.6 Causation Probability

Causation probability has been calculated and provided by IWRAP software. Insufficiencies Bayesian Network is recommended to approximate the causation probability of a risk model. There are several type of calculations to determine the causation probability:

2.6.1 Causation probabilities from literature

In this way, causation probabilities are determined from any researches. For example, Larsen's study of collision between ship and bridges. Larsen also provide the value of ship-ship collision and ship grounding. The table below represents the results.

Table 2.2 Causation probabilities of vessel grounding

Vessel Grounding		
Location	**P_c [x10^{-4}]**	**Comment**
Japanese Straits	[1.0 ; 6.3]	Collisions and grounding
Japanese Straits	1.58	-
Japanese Straits	[0.8 ; 4.3]	-
Dover Straits	1.55	No traffic separation
Dover Straits	1.41	With traffic separation
Straits of Gibraltar	2.2	-
Øresund,Denmark	2.0	-

Table 2.3 Causation probabilities of ship-ship collisions

Ship-ship collisions		
Location	**Pc [x10^{-4}]**	**Comment**
Dover Straits	5.18	Head-on, no traffic separation
Dover Straits	3.15	Head-on, with traffic separation
Øresund,Denmark	0.27	Head-on
Japanese Straits	0.49	Head-on
Japanese Straits	1.23	Crossings
Dover Straits	1.11	Crossings, no traffic separation
Dover Straits	0.95	Crossings, with traffic separation
Straits of Gibraltar	1.2	-
Japanese Straits	1.1	Overtaking
Great Belt, Denmark	1.3	At bends in lanes
Danish water	3.0	Head-on, overtaking, and crossings

2.6.2 Using Bayesian Network

Fault tree analysis and event tree analysis have been used to determine the causation analysis. However, these methods have some disadvantages, 1) difficult to include conditional dependencies and mutually exclusive event in FTA. 2) When the number of variables increase the size of event tree also increases exponentially. 3) If these methods are used to calculate failure mechanism, global model, normally becomes complex analysis. It is impossible to third parties to validate the model. For these reason, it is better to use Bayesian Network to analyze the causation probabilities.

2.7 Consequences Analysis

2.7.1 Ship Collision Consequences

If ship accident happen in a ship traffic. It will be give damage for ship structure. Ship collision is ship collision between 2 ships. First ship is called striking ship (A) and second is called struck ship (B). Ship collision happen when ship A collide ship B. Ship A sail with velocity V_1. Velocity of ship B is V_2 and velocity when collision is V_c at C. ξ, is direction of impact between ship A to ship B. And η is direction of impact between ship B to ship A. In this case, the angle of ship collision is $\beta = \propto$.

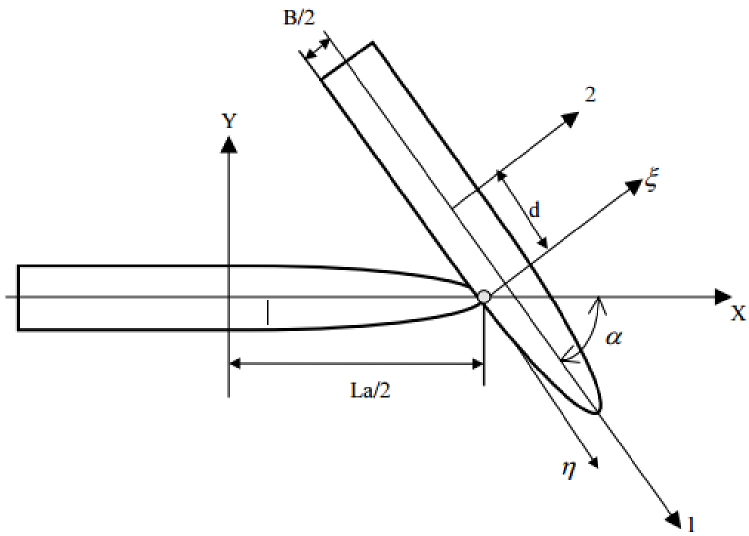

Figure 2.7 Ship Collision Model
Source: (Zhang, 1999)

Thus the equations as follow:

$$x_c - x_a = \frac{L_a}{2} \quad 2.16$$

$$y_c = 0 \tag{2.17}$$

$$x_c - x_b = d.\cos\alpha - \frac{B}{2}.\sin\alpha \tag{2.18}$$

$$y_c - y_b = -d.\sin\alpha - \frac{B}{2}.\cos\alpha \tag{2.19}$$

The assumption value of d equals to 20 m.

$$R_a = \frac{L_a}{4}, R_b = \frac{L_b}{4} \tag{2.20}$$

Thus, the coefficients $D_{\alpha\xi}$, $D_{\alpha\eta}$, $D_{b\xi}$, $D_{b\eta}$, $K_{\alpha\xi}$, $K_{\alpha\eta}$, $K_{b\xi}$, and $K_{b\eta}$ can be calculated with formulas:

$$D_{\alpha\xi} = \frac{1}{1+m_{ax}} sin^2\alpha + \frac{1}{1+m_{ay}} cos^2\alpha + \frac{4}{1+j_a} cos^2\alpha \tag{2.21}$$

$$D_{\alpha\eta} = \left(\frac{1}{1+m_{ax}} - \frac{1}{1+m_{ay}} - \frac{4}{1+j_a}\right)\sin\alpha\cos\alpha \tag{2.22}$$

$$D_{b\xi} = \frac{1}{1+m_{b2}} + \frac{16}{1+j_b}.\left(\frac{d}{L_b}\right)^2 \tag{2.23}$$

$$D_{b\eta} = \frac{8}{1+j_b}.\left(\frac{B.d}{{L_b}^2}\right) \tag{2.24}$$

$$K_{\alpha\xi} = \left(\frac{1}{1+m_{ax}} - \frac{1}{1+m_{ay}} - \frac{4}{1+j_a}\right)\sin\alpha\cos\alpha \tag{2.25}$$

$$K_{\alpha\eta} = \frac{1}{1+m_{ax}} cos^2\alpha + \frac{1}{1+m_{ay}} sin^2\alpha + \frac{4}{1+j_a} sin^2\alpha \tag{2.26}$$

$$K_{b\xi} = \frac{8}{1+j_b}.\left(\frac{B.d}{{L_b}^2}\right) \tag{2.27}$$

$$K_{b\eta} = \frac{1}{1+m_{b1}} + \frac{4}{1+j_b}.\left(\frac{B}{L_b}\right)^2 \tag{2.28}$$

Where:

$$D_\xi = \frac{D_{\alpha\xi}}{M_a} + \frac{D_{b\xi}}{M_b}, D_\eta = \frac{D_{\alpha\eta}}{M_a} + \frac{D_{b\eta}}{M_b} \qquad \text{2.29 and 2.30}$$

$$K_\xi = \frac{K_{\alpha\xi}}{M_a} + \frac{K_{b\xi}}{M_b}, K_\eta = \frac{K_{\alpha\eta}}{M_a} + \frac{K_{b\eta}}{M_b} \qquad \text{2.31 and 2.32}$$

Relative velocity of two ships can be determined as:

$$\xi = V_{ax}\sin\alpha + V_{ay}\cos\alpha + V_{b1}\sin(\beta-\alpha) - V_{b2}\cos(\beta-\alpha)$$

$$\eta = V_{ax}\cos\alpha - V_{ay}\sin\alpha - V_{b1}\cos(\beta-\alpha) - V_{b2}\sin(\beta-\alpha)$$

Because $\beta = \alpha$, equations above can be simplified as:

$$\xi = V_{ax}\sin\alpha + V_{ay}\cos\alpha - V_{b2} \qquad 2.33$$

$$\eta = V_{ax}\cos\alpha - V_{ay}\sin\alpha - V_{b1} \qquad 2.34$$

Losses energy in ship collision can be analyzed as follow:

$$E_\xi = \frac{1}{2}.\frac{M_a/D_\xi}{1+M_a/D_\xi . D_\eta/M_b}\xi^2 \qquad 2.35$$

$$E_\eta = \frac{1}{2}.\frac{M_a/K_\xi}{1+M_a/K_\xi . K_\eta/M_b}\eta^2 \qquad 2.36$$

- Added Mass Coefficients

Added mass coefficients: m_{ax}, m_{ay}, j_a, m_{b1}, m_{b2}, and j_b are the effect of interaction between the ships and seawater, the value of coefficients depend on the ship hull form, duration of impact, and etc. The value of m_{ay}=0.4 – 1.3 and m_{ax}=0.02-0. For the mass coefficient j_a is: j_a=0.21.

2.7.2 Ship Grounding Consequences

Ship grounding problem is divided into 2, there are external dynamics and internal mechanics. Figure below illustrate the division of these problem. Model of external dynamics calculates rigid body motion given force on the ship hull and model of internal mechanics calculates the force on the hull given a certain penetration. (Simonsen, 1997)

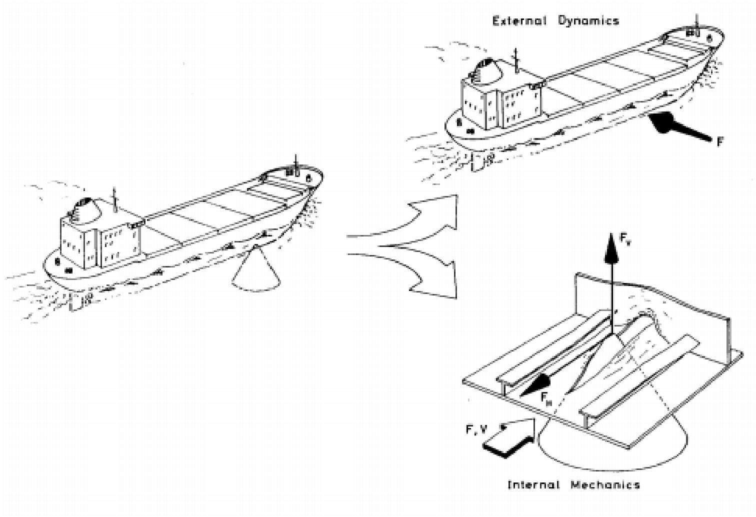

Figure 2.8 Ship Grounding Problem Divisions: External Dynamics and Internal Mechanics
Source: (Simonsen, 1997)

Internal mechanics are separated into energy dissipation by plastic deformation and fracture and energy dissipation by fraction. The given force by obstacles when grounding can be analysis with the value of external dynamics. In this case the obstacles of ship grounding are shipwrecks around Surabaya West Access Channel. The existence of shipwrecks in the waters area can causes ship grounding. The shipwreck body or plate more dangerous than seabed or rock. Body of shipwrecks causes plate deformation until ripped s.

The force of ship grounding depends on ship structure and obstacle/shipwreck structure. The magnitude of force is constant and the direction of ship grounding is opposite with grounded ship's direction.

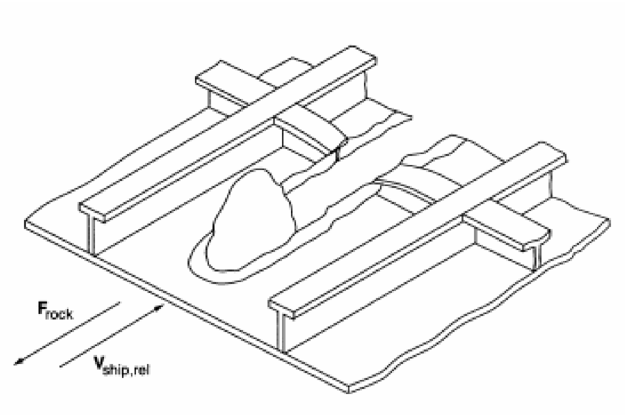

Figure 2.9 The Reaction of Ship Grounding
Source: *(Simonsen, 1997)*

Numerical analysis is used to calculated the magnitude of ship grounding force. Firstly, calculation the magnitude of kinetic energy (E_{kin}). According to the calculation by Simonsen, the maximum distance between ship and obstacle is 26 m (eccentricity of obstacle). Thus, the obstacle cannot effect to the ship hull until 12 m from FP. (Simonsen, 1997)

Considering the magnitude of kinetic energy can be calculated as follow:

$$E_{kin} = \frac{1}{2} M_s v^2 \tag{2.37}$$

The ship grounding force is given by shipwrecks with stopping distances approximately 25, 50, 75, 100 m. Thus, ship grounding force (F_G) can be calculated as follow:

$$F_G = \frac{E_{kin}}{d} \tag{2.38}$$

CHAPTER 3
METHODOLOGY

3.1 Methodology Flowchart

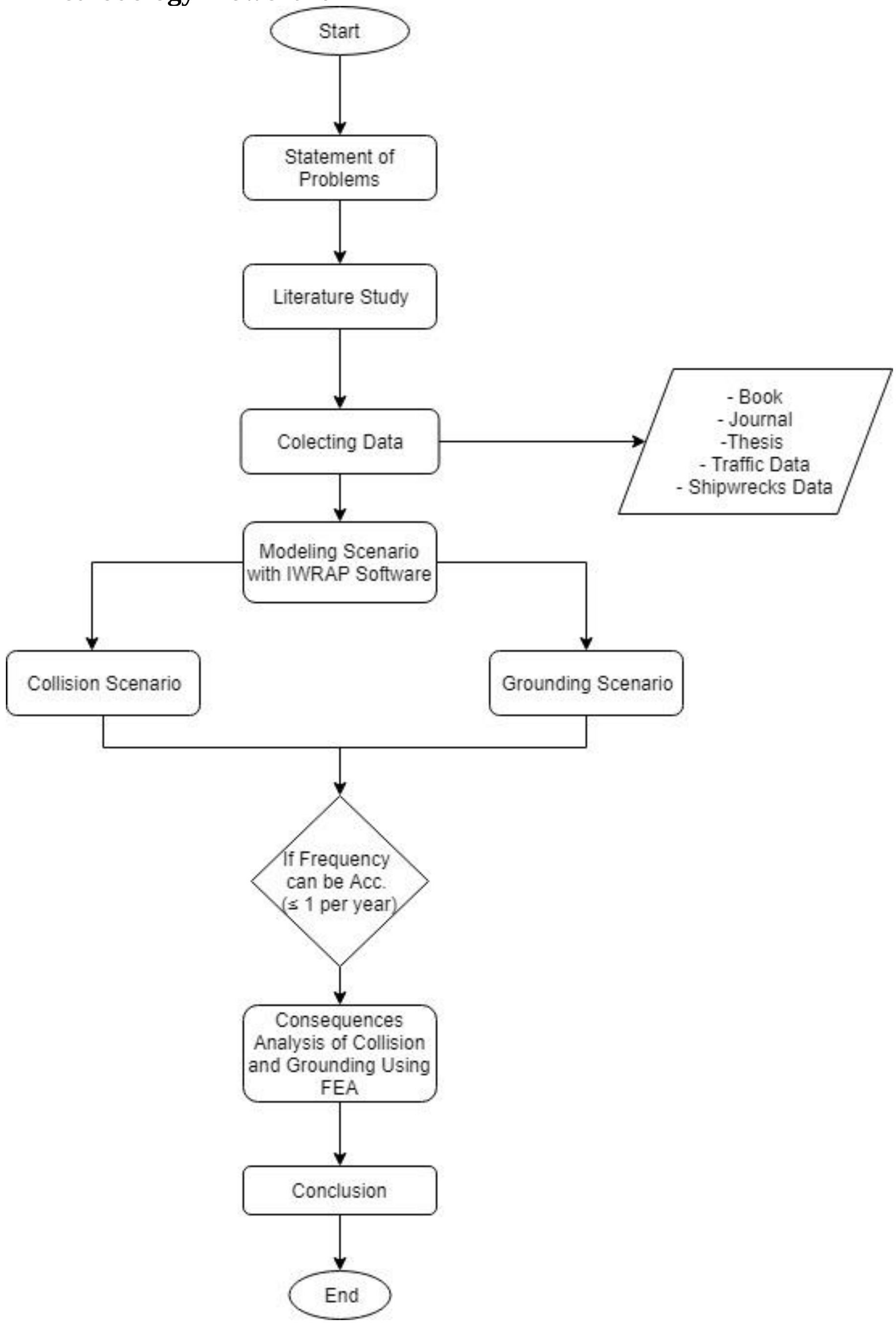

Figure 3.1 Flow Chart

3.2 Statement of Problem

This stage is an early stage in starting this bachelor thesis. At this stage the problems that occur are arranged to determine what solutions can be done. With the existence of these problems can be determined the purpose of making this bachelor thesis.

3.3 Literature Study

After the preparation of the problem, then conducted literature study to analyze what methods can be used to solve the problem. From the various literatures are collected into one so as to produce the method of completion. The literature used can be derived from journal, media, bachelor thesis or research that has been done before, and from related books. Literature-related issues can be used as a reference in solving the problem.

3.4 Collecting data

After conducting a literature study, then the data collection related to the problem and its completion. These data include, AIS data, shipwreck data located on SWAC, and other related data. The collected data is used to support the method in solving the problem. With this data collection is expected to solve the problem can be resolved properly.

3.5 Analysis the Scenario Using IWRAP

IWRAP is a software that is used to model the risk assessment of maritime issues. In this bachelor thesis will use IWRAP Mk2, the application aims to provide users with an application that helps in the calculation of risk involving shipwreck in a region of aquatic waters. Users can evaluate and estimate the magnitude of the annual frequency of collisions or grounding in the area. At the time of analysis, first do the modeling of the desired area. This modeling consists of waypoints and legs, such as traffic lanes. The figure below shows the modeling of 1 leg and 2 waypoints.

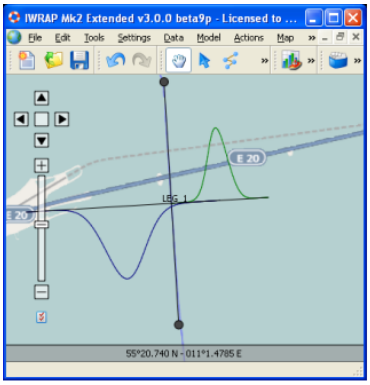

Figure 3.2 Basic Concept of IWRAP
Source: *(Engberg, 2015)*

According to Figure 3.2, leg have 2 direction that is, north or south. In each direction is determined large of the lateral distribution and traffic volume. Lateral distribution is a large distribution of the distribution of each direction that the ship will pass, for example if each direction is distributed using normal distribution. However, the average size and standard deviation is greater in the south, then the south will have many frequencies from the ship to the north. In IWRAP Mk2 can be used various types of distribution such as, Normal distribution, Weibull distribution, Lognormal, and Beta distribution.

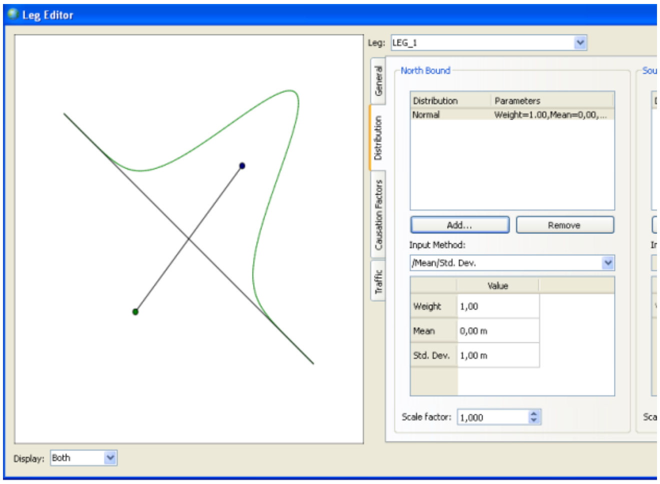

Figure 3.3 IWRAP Model using Normal Distribution
Source: (Engberg, 2015)

IWRAP Mk2 also features a causation factor, causation factor determines the cause of a failure. Causation factors play an important role in determining outcomes, because the causation factor acts as a reduction factor in the number of blind accident calculations. IWRAP Mk2 has set the causation factor for each occurrence, for example during collision and grounding. However, the causal factor value of IALA is not recommended, so the user needs to enter its own value of causation factor.

In IWRAP Mk2 also set about setting Traffic Volume. Traffic volume is set in every direction of the leg. The distribution of the traffic volume itself is defined as the annual number of vessels operating in the leg in a particular direction. The figure below shows the distribution of ships in a year to the north. The sum of the operations is a function of the type and length of the vessel. For example on one ship product oil tankers with a length of 100-125 is as much as 250, then fill in the amount of 250 on oil product tank columns with a length of 100-125.

In addition to accidents caused by human error as well as many collision and ground collision accidents caused by drifting. The two main causes of drifting are rudder stuck and black out. Black outs have a bigger share in the matter. Blackout can be caused by fuel contamination, internal fault on the main engine, or failure of the electrical system. Damage will be more severe if the blackout occurs in a vulnerable area, for example in the area of many obstacles. The obstacle in this case is the wreck, because at SWAC there are 22 shipwrecks. Blackout that occurs will cause drifting vessels that can cause the ship experienced collisions and grounding. Accidents caused by this drifting can be mitigated by using an anchor or by calling a Tug boat. Failure of the propulsion system may appear in leg.

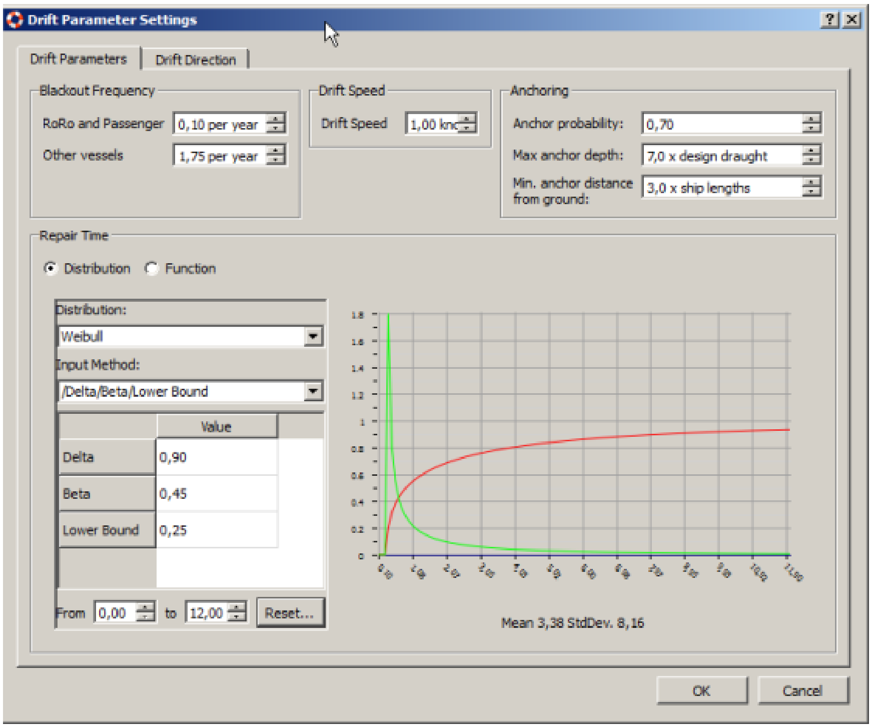

Figure 3.4 Drifting Setting in IWRAP Mk2
Source: (Engberg, 2015)

3.6 Calculating the Frequencies of Collision and Grounding

After modeling the collision and grounding accidents, we can calculate the value of frequencies of collision and grounding. The accepted value of frequency is less than 1 per year (≤ 1 per year). If the calculating number of frequency can be raised, the analyzing consequence will be done. If the frequency is more than one, the scenario of accidents will be conducted again.

3.7 Consequence Analysis of Collision and Grounding Using FEA

The results of consequences of ship accident can be torn plate, ship sinking, oil Pollution, and dead. According to (Burmeister, 2007) there are 2 types of consequences of ship accident. Firstly, external dynamics is the movement of ship accident. And secondly, internal mechanics is process of ship deformation and damage during ship accident. External dynamics can be solved by several approximately, there are:

- Numerical approach, external dynamics is analyzed by some numerical equations.
- Analytical approach, experiment or modeling is used to analyze the problems.

In this bachelor thesis FEA is used to modeling the ship accident, ship collision or ship grounding.

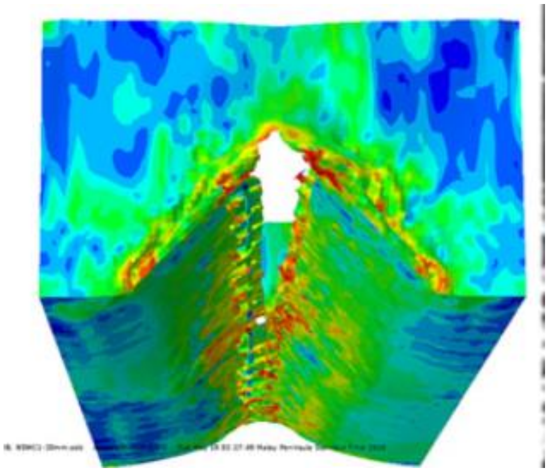

Figure 3.5 FEA Simulation in Double Bottom
Source: (Anuar AbuBakar, 2011)

Finite Element Analysis is a method to solve engineering problems, in addition stability analysis, heat transfer, fluid flow, potential electromagnetic. Many factors affect the accuracy of FEA, one of which is the mesh density. In problems involving material damage, mesh density is a very important factor.

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CHAPTER 4
DATA ANALYSIS AND RESULT

In this bachelor thesis, the frequency of ship collisions and ships grounding due to the wreck around SWAC will be analyzed using IWRAP and manual calculations. Analysis on the IWRAP software will be carried out with several collision scenarios and ship grounding, including head-on collision, overtaking collision, and crossing collision for ship collision. Meanwhile, the powered grounding and drifting grounding scenarios will be used to analyze the ship grounding. The data used in this analysis is data of the existence of shipwrecks obtained from *Kesatuan Penjagaan Laut dan Pantai Indonesia (KPLP)* and AIS data from 2017-2018 around SWAC.

Head-on collision is one type of ship collision scenarios that occurs between two ships sailing in the same path as the opposite direction of the ship's motion. The width of the SWAC route is 150 m with a depth of 8.5 LWS. The existence of shipwrecks around the route will have an impact on ship traffic conditions. For example, when a sailing vessel wants to avoid a shipwreck that is in front of it, the vessel will change the direction of motion of the ship so that it can collide other ships.

Then, for overtaking collision itself is defined as a collision that occurs between two ships that cross the same route and direction. The collision occurred when the ship was about to overtake the ship that was in front of her. Shipwrecks will narrow the width of the existing path way, so the chances of overtaking collision will be greater. Crossing collision occurs as a result of vessels sailing on different path ways, vessels on path way one can collide vessels on other path ways and vice versa. Crossing collision between two vessels can occur with different degrees of collision, depending on the direction of the motion of the ship itself. The existence of the shipwrecks will increase the chances of crossing collision.

Powered grounding scenarios caused by human errors and unexpected problems, so sailing ships cannot avoid the wreck that acts as an obstacles. Meanwhile for drifting grounding is a scenario of ship grounding due to damage of ship propulsion, mechanical damage of ship, and damage of the ship's electricity. This caused the ship to blackout and eventually drifted to cause the ship to run aground.

4.1 Shipwrecks Exist In SWAC

According to data from Dinas Hidro-Oceanografi 2017 there are any 22 shipwrecks around the SWAC. Almost shipwrecks are unknown ships. Because, most of shipwrecks are heritage from Hindia Belanda government. Actually, there are more than 22 shipwrecks in the waters, however the Indonesia government have been lifted the other shipwrecks. Indonesia’s government have been auctioned more than 15 shipwrecks to companies. For example is shipwrecks with code 50-M, 52-M, Ex Kawitan, and ship with known ship name there are KM Tanto Niaga, KM Lautan Berkah, KM Alphine, KM Journey, and KM Wihan Sejahtera to their companies.

Table 4.1 Unnamed shipwrecks around SWAC

No	Code	Dimension (m)	Ship Type	Depth (m)	Condition	Coordinate	
						Latitude	Longitude
1	Bouy A	Unknown	Unknown	-	As guide bouy	-7.189	112.721
2	Bouy B	Unknown	Unknown	-	As guide bouy	-7.188	112.727
3	Bouy C	Unknown	Unknown	-	As guide bouy	-7.184	112.727
4	S-6	26,5 x 6 x -	Ponton	14	Wreck enters mud ± 1 m along 26 m	-7.204	112.728
5	S-7	17 x 5,5 x -	Layar PLM	14		-7.204	112.728
6	47-M	153 x 17 x 11	Passenger /Cargo	26	Upright position, embedded ± 5m	-7.184	112.718
7	41-M	94 x 11,5 x 9	Cargo	27	Tilt at Stbd ± 110º	-7.189	112.729
8	S-37	86 x 13 x 10	Cargo	21	Tilt at Prstd ± 70º	-7.188	112.723
9	46-M	140 x 17 x 10	Cargo	25	Stand upright	-7.187	112.721
10	48-M	92 x 13 x 7	Cargo	20	Stand upright	-7.187	112.723
11	51-M	28 x 13 x 7	Cargo	20	Tilt at Prstd ± 70º	-7.184	112.727
12	53-M	108 x 15 x 8	Passenger /Cargo	25	Tilt at Stbd ± 58º	-7.188	112.731
13	57-M	147 x 14 x 10	Cargo	14	Tilt at Stbd ± 45º	-7.198	112.743
14	S-36	54 x 10 x 6	Passenger /Cargo	20	Tilt at Stbd ± 90º	-7.18416	112.717
15	S-13	5 x 3 x 0,5	Unknown	9	Tilt at seabed ± 5m	-7.187	112.718
16	S-16	38 x 75 x 3	Keruk Tambora	4	Stomach position	-7.182	112.717
17	S-19	Unknown	Dumping Ground	3	Wreck full with mud	-7.182	112.711

Continuance of Table 4.1

18	S-21	Unknown	Dumping Ground	3	Wreck full with mud	-7.178	112.729
19	S-22	Unknown	Dumping Ground	14	Wreck full with mud	-7.176	112.729
20	Ex Numang-guri	59,9 x11,4 x 6,15	Passenger	21	Tilt at Stbd ± 45^o	-7.189	112.722
21	Ex Ocean Concord	81,5 x 15 x 6,7	Container	8	Tilt at Prstd ± 65^o	-7.171	112.696
22	Ex Tipison	94 x 15,73 x 8,01	Cargo	23	Tilt at Stbd ± 10^o	-7.177	112.680

Table 4.2 Lifted shipwrecks around Surabaya West Access Channel

No	Name/Code	Dimension (m)	Ship Type	Depth (m)	Condition	Coordinate	
						Latitude	Longitude
1	50-M	135 x 18 x 10	Tanker	20	Lifted	-7.18389	112.7261
2	52-M	89 x 11 x 7	Cargo	18	Lifted	-7.18731	112.7283
3	Ex Kawitan	60 x 10 x 6	Cargo	14	Lifted	-7.18389	112.7247
4	KM Tanto Niaga	Unknown	Cargo	-	Lifted	-7.20667	112.7225
5	Km Lautan Berkah	55 x 9 x 5	Cargo	-	Lifted	-6.96166	112.8161
6	KM Alphine	118x20x9	Cargo	-	Lifted	-7.37222	112.9475
7	KM Journey	85 x 7 x -	Cargo	-	Lifted	-7.15129	112.6741

Continuance of Table 4.2

8	KM Wihan Sejahtera	115 x 22 x 15	Passenger	15-20	Lifted	-7.18835	112.8006
9	Unknown	-	-	-	Lifted	-6.88555	112.74083
10	Unknown	-	-	-	Lifted	-6.88611	112.7394
11	Unknown	-	-	-	Lifted	-6.96806	112.715

Tables above illustrate total, condition, depth, and coordinate of shipwrecks, with these tables we can plotting shipwrecks in the map to know the position of shipwrecks depend to Surabaya West Access Channel (SWAC) route. Plotting is used to analyze the location of shipwreck from SWAC route, this analysis aim to determine vulnerable points. Thus, we can determine whichever of shipwrecks that give more impact to ship accident (ship collisions and groundings).

4.2 Shipwrecks Plotting

To knowing the position of shipwrecks, we have to plotting the shipwreck coordinates to map and also plotting the coordinates of Surabaya West Access Channel route. This plotting will illustrate the distance and distribution of shipwrecks. According to KM PERHUBUNGAN KP 455 Tahun 2016, there are the coordinates of Surabaya West Access Channel.

Table 4.3 Surabaya West Access Channel Coordinates

No	**Latitude**	**Longitude**	**No**	**Latitude**	**Longitude**
Branching Route					
1A	-6.633	112.629	1B	-6.599	112.687
2A	-6.770	112.744	2B	-6.769	112.745
New Route					
3A	-6.824	112.744	3B	-6.825	112.745
4A	-6.861	112.744	4B	-6.862	112.745
5A	-6.889	112.735	5B	-6.889	112.736
Old Route					
6A	-6.969	112.706	6B	6.970	112.707
7A	-7.000	112.685	7B	-7.001	112.685
8A	-7.013	112.675	8B	-7.014	112.676
9A	-7.033	112.666	9B	-7.034	112.667
10A	-7.085	112.666	10B	-7.085	112.657
11A	-7.1085236	112.657293	11B	-7.108436388	112.658648056
12A	-7.12738	112.65851	12B	-7.127044166	112.659849167
13A	-7.1778388	112.682444	13B	-7.176947222	112.683494445
14A	-7.1887444	112.69736389	14B	7.187522222	112.697975
15A	-7.1938880	112.71483833	15B	-7.192503056	112.71508722
16A	-7.192975	112.73418611	16B	-7.191619445	112.73412223

Table 4.4 Anchoring Area Coordinates

No	**Latitude**	**Longitude**
A.1	-7.1783556	112.714186
A.2	-7.1784889	112.720472
A.3	-7.1913222	112.730038
A.4	7.19060556	112.714194

Tables above illustrates the boundary of Surabaya West Access Channel Route and Anchoring Area. All coordinates above will be plotting into map to get the picture of distribution of shipwrecks around Surabaya West Access Channel and the position from anchoring area. Because, location of most of the shipwrecks inside the anchoring area. It is dangerous for ship, because ship have to avoid the shipwrecks when they want to anchor.

Figure below describes the location and distribution of shipwrecks. Red point illustrate the location of shipwreck, the total of shipwrecks are 22 units. Black line describe the route of SWAC, from figure above there is one shipwreck close with route. This shipwreck have big potential as the cause of ship accident. The yellow is illustrate anchoring area. In the anchoring area, there are any 10 shipwrecks. These shipwreck will impact to the ship that want to anchor. With the existence of 10 shipwrecks inside the anchoring area involve reduced of anchoring area until 50%. It is will give dangerous effect to ship traffic (caused ship collision or ship grounding).

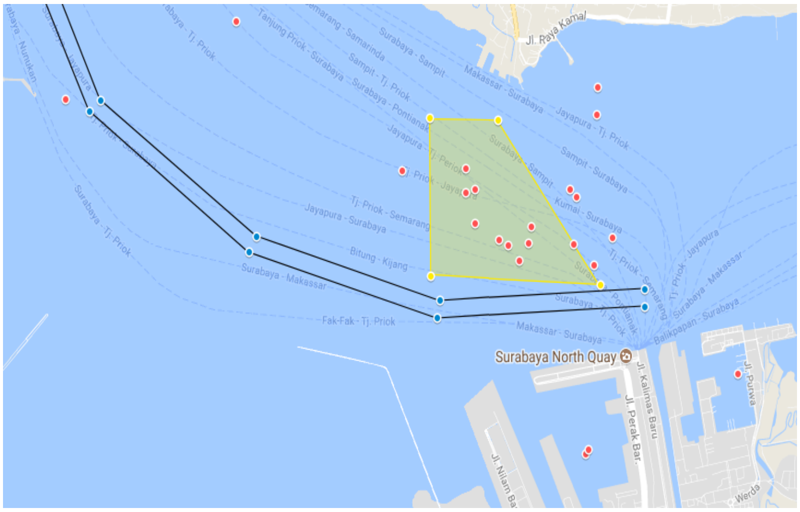

Figure 4.1 Location of Shipwrecks Around Surabaya West Access Channel

4.3 Data of Ships

Ship clustering data is used to analyze the frequencies of ship accidents. In this case, data used to analyze from 2015. Because, the existence of shipwrecks for this case in 2017, thus ship clustering data in 2017 have to analyze. To analyze the ship clustering in 2017, forecasting method is used to analyze ship clustering in 2017.

Forecasting itself is defined as process of predicting a future event, for example to analyze production, inventory, personnel, or facilities. To analyze clustering ship in 2017, firstly deciding the kind of forecasting type. Time series is chosen for analyze the data. Firstly, we have to determine the kind of curve of the data. Then, calculate the variables using some formulas.

Table 4.5 Ship Units around SWAC

Year	Ship Units
2012	74,915
2013	78,189
2014	78,778
2015	66,923
2016	62,091

Data above is obtained from annual report of PT. PELINDO III. To know the ship units in 2017, we have to draw the curve of data above. The curve aim to analyze the forecasting method.

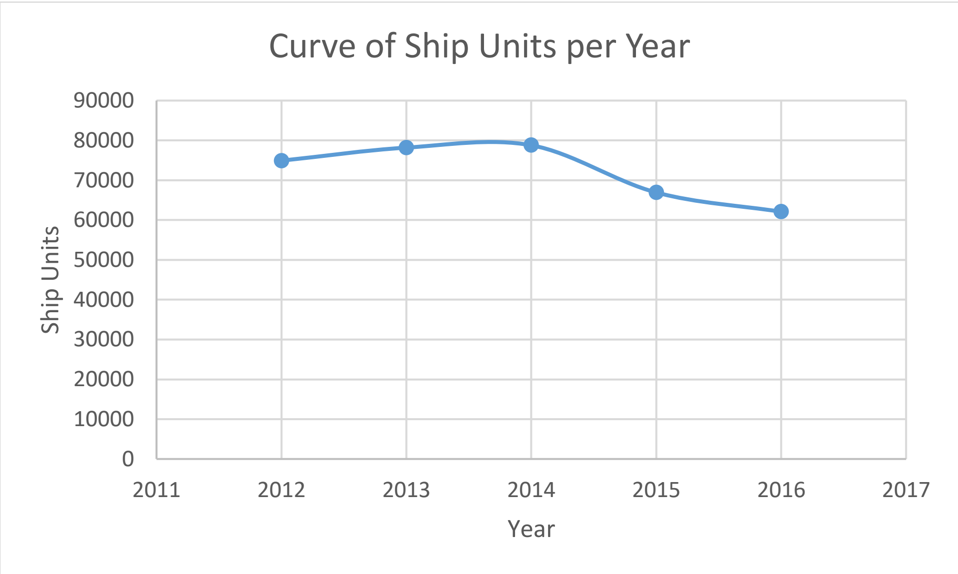

Figure 4.2 Curve of Ship Units per Year

According to curve above, the ship units per year around SWAC decrease. Although, for 2012 to 2014 the units increase. Thus, linear time series is used to analyze for forecasting method. There are the calculation of forecasting method:

- Finding the trend line

Year	Time Period	Ship Units	x^2	xy
2012	1	74915	1	74915
2013	2	78189	4	156378
2014	3	78778	9	236334
2015	4	66923	16	267692
2016	5	62091	25	310455
Total	15	360896	55	1045774

$$\bar{x} = \frac{\sum x}{n} = \frac{15}{5} = 3 \qquad \bar{y} = \frac{\sum y}{n} = \frac{360896}{5} = 72179.2$$

$$b = \frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2} = \frac{1045774 - 5\ x\ 3\ x\ 72179.2}{55 - 5\ x\ 15^2} = -922.85$$

$$a = \bar{y} - b\bar{x} = 72179.2 - (-922.85)\ x\ 3 = 74947.75$$

Thus, ship units in 2017 equals to = a + n_i x b= 74947.75 + 6 x (-922.85) = 69410.65 ≈ 69411 units

Because, the collected data is ship clustering in 2015. Ratio between ship units in 2017 and 2015 will be calculate to analyze ship clustering in 2017. Thus, the ratio of ship units in 2017 and 2015 equals to 69411/66923 = 1.037. Then, all data of ship clustering in 2015 will be multiplied by 1.037.

Table 4.6 Ship Clustering in 2015

Length	**Ship Types**						
	Product Tanker	**Container**	**Ro-Ro**	**Other Vessels**	**Support Ship**	**General Cargo**	**Passenger**
0-25	3	0	0	0	10	3	0
25-50	178	27	26	0	231	375	65
50-75	319	278	182	0	231	776	36
75-100	242	1267	189	0	14	267	206
100-125	84	1157	539	0	1	64	17
125-150	37	586	105	0	0	10	355
150-175	90	151	57	0	0	9	4
175-200	29	40	0	0	0	15	0
200-225	0	0	0	0	0	1	0
225-250	0	0	0	0	0	0	0
250-275	0	0	0	0	0	0	0
275-300	0	0	0	0	0	0	0

Table 4.7 Ship Clustering in 2017, After Forecasting

Length	Ship Types						
	Product Tanker	Contain er	Ro-Ro	Other Vessels	Support Ship	Gener al Cargo	Passen ger
0-25	3	0	0	0	10	3	0
25-50	185	28	27	0	240	389	67
50-75	331	288	189	0	240	805	37
75-100	251	1314	196	0	15	277	214
100-125	87	1200	559	0	1	66	18
125-150	38	608	109	0	0	10	368
150-175	93	157	59	0	0	9	4
175-200	30	42	0	0	0	15	0
200-225	0	0	0	0	0	1	0
225-250	0	0	0	0	0	0	0
250-275	0	0	0	0	0	0	0
275-300	0	0	0	0	0	0	0

4.4 Ship Collision and Grounding Scenario

Ship collision scenarios occur around the shipwrecks. This is because the existence of shipwrecks causes the narrowing of the grooves. So, the chance of the collision of the ship becomes larger. Most shipwrecks are in the anchoring area. Ship collisions may occur between ships that will go to ports with ships going out of the harbor. Ship collision can also be caused by a vessel that will go to the anchoring area with the ship going out or the vessel going to harbor.

The figure below illustrates the scenario of the ship's collision and grounding. Head on and overtaking collisions can occur between ships in leg 3. Whereas, crossing collisions can occur between ships in leg 1 with vessels in leg 2 with 90 track angles, then between leg 1 with leg 3 with 120 track angles, and between leg 2 and 3 with 30 track angles.

The reduction of width of the route is a major factor in the ship collision. The existence of shipwrecks on the above seabed around SWAC becomes a barrier for ship’s voyage. Even more, it causes the ship grounding. Damage of the ship grounded by the existence of shipwrecks is very dangerous, because the material of shipwrecks made of steel. Thus, give more damage to the hull of the grounded ship.

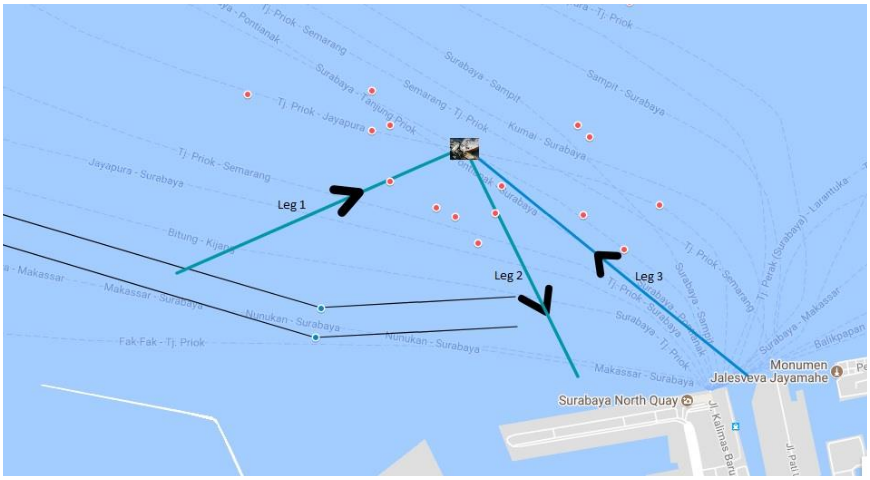

Figure 4.3 Ship Collision and Grounding Scenario

Ship grounding can occur in the anchoring area. Because in this area there are many shipwrecks. For example, powered grounding can occur due to a ship collision. Therefore, the struck ship move and grounding or the existence of human error in taking the route. Meanwhile, drifting grounding can occur because of the blackout or no anchoring, this condition due to ship grounding.

4.5 IWRAP Analysis

IWRAP analysis is used to analyze the frequencies of each collision and grounding scenarios. Manual calculation analysis of these scenarios are based on IWRAP theory. AIS data is used to know density plot of ship traffic around SWAC. Figure 4.4 illustrates the density plot of distribution of ship traffic and the existence of shipwrecks. The density plot of ship traffic is obtained from AIS data in 2017-2018. With this density plot shipwrecks that have greater potential for ship accidents can be analyzed.

The red part is part of the amount of heavy ship traffic, as seen in the picture of the red area found in the main channel of SWAC. In addition to the red color there is also a blue color near the port. The blue color shows a higher amount of traffic than red part. In addition to red and blue, there is also a yellow color around the SWAC. This indicates that many ships are passing through the path way. Besides that the number of shipwrecks that are outside the groove is many more, causing a greater chance of accident.

For example in the anchoring area (which is circled) there are 15 shipwreck. Because in that area many ships that sailed (were proven in yellow color), so in that area there was a high chance of a ship accident. The shipwreck contained in SWAC is illustrated with a blue box. Based on the data, the largest size of the wreck is 57 M with a size of 147 x 14 x 10 m. There are 22 shipwrecks in SWAC.

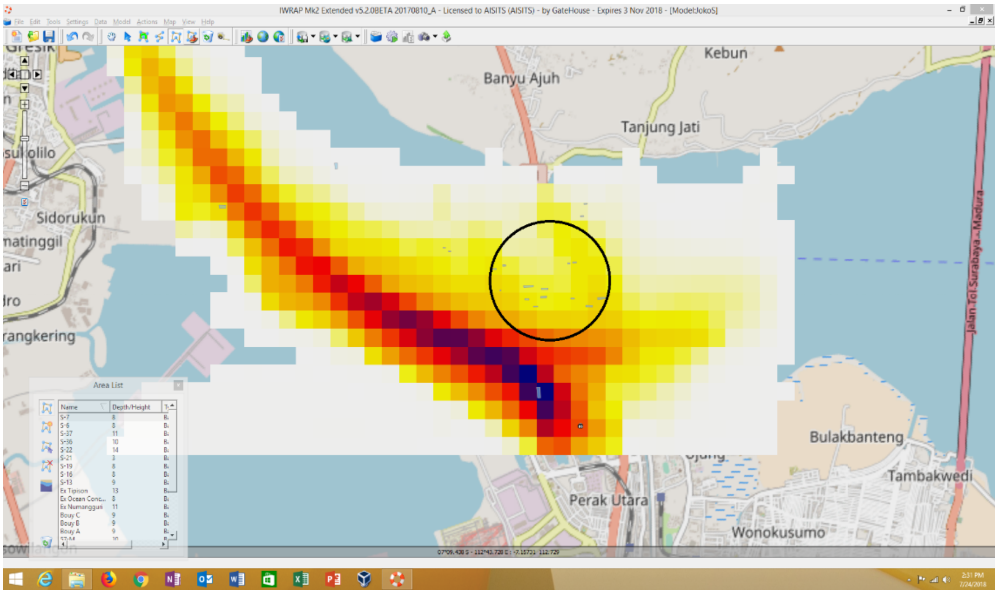

Figure 4.4 Formed Ship Traffic using IWRAP Software

4.5.1 Head-on Collision

Manual calculation of Head-on Collision aim to validate the analysis of IWRAP software. Calculation base on IWRAP theory is written by Peter Friis-Hansen. Length of segment is very important to calculate the frequency, Lw define 1000 m. The calculation of this collision is simulated by *i* and *j* direction. There are notations in this analysis:

L_i, B_i, v_i, Q_i: represent length, breadth, velocity, total of ship for direction *i*.
L_j, B_j, v_j, Q_j: represent length, breadth, velocity, total of ship for direction *j*.

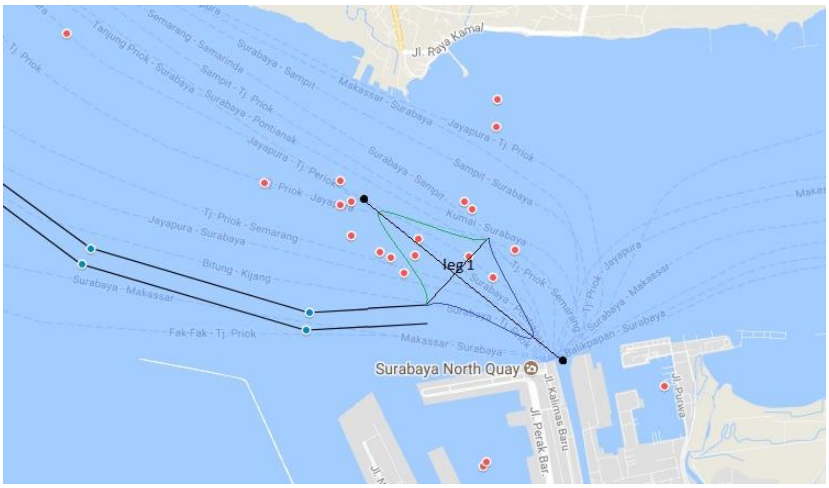

Figure 4.5 Head-on and Overtaking Collision Scenario

- Example of calculation of head-on collision, there are data to analyze the collision:

  Length of segment (L_w) : 1000 m
  Length of ship in *i* direction (L_i) : 89 m
  Breadth of ship in *i* direction (B_i) : 14.908m
  Length of ship in *j* direction (L_j) : 111 m
  Breadth of ship in *j* direction (B_j) : 17.788m
  Total of ship in *i* direction (Q_i) : 251
  Total of ship in *j* direction (Q_j) : 87
  Velocity of ship in *i* direction (V_i) : 8.5 kts = 4.37 m/s
  Velocity of ship in *i* direction (V_j) : 7.5 kts = 3.86 m/s
  Center of ship's path way of ship *i* (μ_i) : 0
  Center of ship's path way of ship *j* (μ_j) : 0
  Standard deviation of ship in *i* direction (σ_i) : 75
  Standard deviation of ship in *j* direction (σ_j) : 75

- Relative speed between vessels, $V_{ij} = V_i + V_j$:

$$V_{ij} = V_i + V_j$$
$$V_{ij} = 4.37 + 3.86$$
$$= 8.23 \quad \text{m/s}$$

- Average width of vessels, B_{ij}:

$$Bij = \left(\frac{Bi + Bj}{2}\right)$$
$$Bij = \left(\frac{14.908 + 17.788}{2}\right)$$
$$= 16.348 \qquad \text{m}$$

- Average of sailing distance of two vessels, μ_{ij}:

$$\mu_{ij} = \mu_i + \mu_j$$
$$= 0 + 0$$
$$= 0$$

- Standard deviation of joint distribution, σ_{ij} :

$$\sigma_{ij} = \sqrt{\sigma_i{}^2 + \sigma_j{}^2}$$
$$= \sqrt{75^2 + 75^2}$$
$$= 106.066$$

- Collision probability, P_G:

$$P_G = \phi\left(\frac{Bij - \mu ij}{\sigma ij}\right) - \phi\left(-\frac{Bij + \mu ij}{\sigma ij}\right)$$
$$= \phi\left(\frac{14.908 - 0}{106.006}\right) - \phi\left(-\frac{17.788 + 0}{106.006}\right)$$
$$= 0.56125 - 0.43875$$
$$= 0.12249$$

- Geometric number as candidates of head-on collision, N_G:

$$N_G^{head-on} = Lw \sum P_{Gi.j}^{head-on} \frac{V_{ij}}{V_i V_j} (Q_i Q_j)$$
$$= 1000\ x\ 0.12249\ \frac{8.23}{16.868} (251\ x\ 87)$$
$$= 0.0414$$

- The frequency of head-on collision, λ:

$\lambda = P_c\ x\ N_G$ *,where P_C equals to 0.00005 base IWRAP theory*
$= 0.0005 \text{ x } 0.0414$
$= 2.07 \cdot 10^{-6}$

All calculations above will be done for 41 data of ship clustering, the total of the calculated frequencies is the frequency of head-on ship collision.

Frequency of head-on collision from manual calculation, λ_{manual}= **$6.99 \cdot 10^{-3}$**
Frequency of head-on collision from IWRAP, λ_{IWRAP} = **$7.07 \cdot 10^{-3}$**

4.5.2 Overtaking Collision

Overtaking collision is simulated in same area with head-on collision. This collision is simulated with 2 different ship, there are ship *i* and ship *j*. The length of segment also important to analyze this collision, given Lw is 1000 m. The direction of ships is west to east. There are example of calculation of frequency of overtaking collision.

➢ Example of calculation of overtaking collision, there are data to analyze the collision:

Length of segment (L_w)	: 1000 m
Length of ship in *i* direction (L_i)	: 65 m
Breadth of ship in *i* direction (B_i)	: 11.364m
Length of ship in *j* direction (L_j)	: 137 m
Breadth of ship in *j* direction (B_j)	: 21.34 m
Total of ship in *i* direction (Q_i)	: 331
Total of ship in *j* direction (Q_j)	: 38

Velocity of ship in *i* direction (V_i) : 12 kts = 6.173 m/s
Velocity of ship in *i* direction (V_j) : 10 kts = 5.144 m/s
Center of ship's path way of ship *i* (μ_i) : 0
Center of ship's path way of ship *j* (μ_j) : 0
Standard deviation of ship in *i* direction (σ_i) : 75
Standard deviation of ship in *j* direction (σ_j) : 75

- Relative speed between vessels, V_{ij}:

$$V_{ij} = V_i - V_j$$
$$V_{ij} = 6.173 - 5.144$$
$$= 1.0288 \quad \text{m/s}$$

- Average width of vessels, B_{ij}:

$$Bij = \left(\frac{Bi + Bj}{2}\right)$$
$$Bij = \left(\frac{11.364 + 21.34}{2}\right)$$
$$= 16.352 \quad \text{m}$$

- Average of sailing distance of two vessels, μ_{ij}:

$$\mu_{ij} = \mu_i + \mu_j$$
$$= 0 + 0$$
$$= 0$$

- Standard deviation of joint distribution, σ_{ij} :

$$\sigma_{ij} = \sqrt{\sigma_i{}^2 + \sigma_j{}^2}$$
$$= \sqrt{75^2 + 75^2}$$
$$= 106.066$$

- Collision probability, P_G:

$$P_G = \phi\left(\frac{Bij - \mu ij}{\sigma ij}\right) - \phi\left(-\frac{Bij + \mu ij}{\sigma ij}\right)$$
$$= \phi\left(\frac{16.352 - 0}{106.066}\right) - \phi\left(-\frac{16.352 + 0}{106.066}\right)$$
$$= 0.5612 - 0.4387$$
$$= 0.12252$$

- Geometric number as candidates of overtaking collision, N_G:

$$N_G^{head-on} = Lw \sum P_{Gi.j}^{head-on} \frac{V_{ij}}{V_i V_j} \left(Q_i Q_j\right)$$

$$= 1000\ x\ 0.12252\ \frac{1.0288}{31.754}(331\ x\ 38)$$
$$= 0.001583$$

- The frequency of overtaking collision, λ:

  λ $= P_c\ x\ N_G$ *,where P_C equals to 0.00011 base IWRAP theory*

  $= 0.00011\ x\ 0.001583$

  $= 1.74 \cdot 10^{-7}$

All vessels in the clustering data will be calculated by the above method. So it generates a large frequency as follows:

Frequency of overtaking collision manual calculation, λ_{manual}= **$1.02 \cdot 10^{-3}$**
Frequency of overtaking collision from IWRAP, λ_{IWRAP} = **$9.04 \cdot 10^{-4}$**

4.5.3 Crossing Collision

Ships will be divided into 2 distributions, there are *i* and *j*. These distributions represent the traffic of ship around Surabaya West Access Channel, crossing collision will be modelled with these distributions. In crossing collision there is an angel of tracks. Crossing collision will be simulated in three angles of tracks, they are 30°, 90° , and 120°. It aims to analyze the frequencies of crossing in any condition of angles of track. To analyze the frequency of crossing ship collision there are some calculation. The calculation aim to validate frequency from IWRAP software analysis.

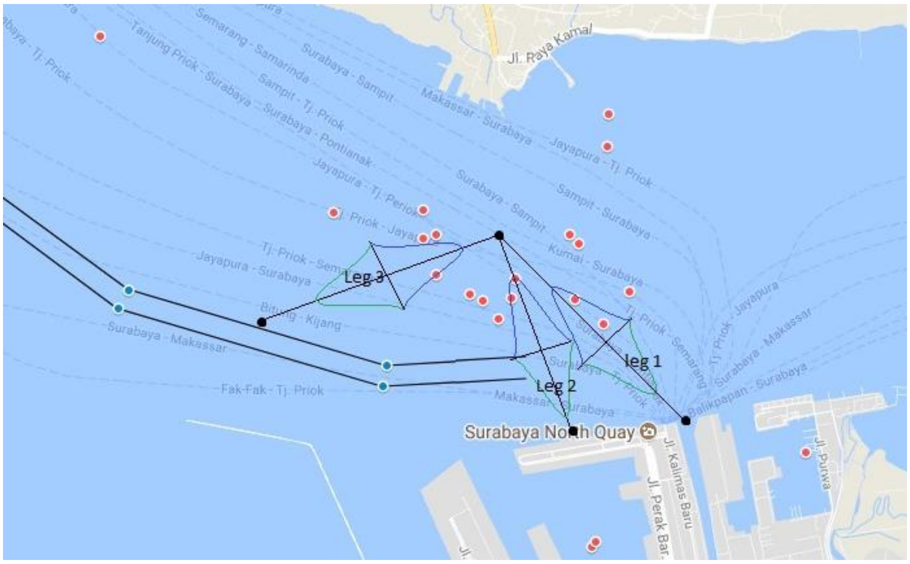

Figure 4.6 Crossing Collision Scenario

- Example of calculation of crossing collision with track angle equals to 30^o, in this case calculation of crossing collision is analyzed using ship with average length of ships are 114 m and 137 m. There are required data to analyze the collision:

Average length of ship in *i* direction (L_i)	: 24	m
Average breadth of ship in *i* direction (B_i)	: 6.997	m
Average length of ship in *j* direction (L_j)	: 39	m
Average breadth of ship in *j* direction (B_j)	: 8.108	m
Total of ship in *i* direction (Q_i)	: 3	units
Total of ship in *j* direction (Q_j)	: 185	units
Velocity of ship in *i* direction (V_i)	: 6 kts = 3.09 m/s	
Velocity of ship in *i* direction (V_j)	: 5 kts = 2.572 m/s	
Center of ship's path way of ship i (μ_i)	: 0	
Center of ship's path way of ship *j* (μ_j)	: 0	
Standard deviation of ship in *i* direction (σ_i)	: 75	
Standard deviation of ship in *j* direction (σ_j)	: 75	
Track angle, (θ)	: 30^o	
Sin θ	: 0.5	
Cos θ	: 0.867	

- Relative velocity, V_{ij}:

$$V_{ij} = \sqrt{(V_i)^2 + (V_j)^2 - 2V_iV_jcos\theta}$$

$$= \sqrt{(3.09)^2 + (2.572)^2 - 2\ x\ 3.09\ x\ 2.572\ x\ 0.867}$$

$$= 1.547 \text{ m/s}$$

- Collision diameter, D_{ij}:

$$D_{ij} = \frac{L_iV_j + L_jV_i}{V_{ij}}\sin\theta + B_j\left\{1 - \left(\sin\theta\frac{V_i}{V_{ij}}\right)^2\right\}^{1/2} + B_i\left\{1 - \left(\sin\theta\frac{V_i}{V_{ij}}\right)^2\right\}^{1/2}$$

$$= \frac{24x2.572 + 39x3.09}{1.547}\ 0.5 + 8.108\left\{1 - \left(0.5\,x\frac{2.572}{1.547}\right)^2\right\}^{1/2} + 6.997\left\{1 - \left(0.5\,x\frac{3.09}{1.547}\right)^2\right\}^{1/2}$$

$$= 102.51 \quad \text{m}$$

- Numerical geometry as candidates of crossing collision, N_G:

$$N_G^{crossing} = \sum_{i.j}\frac{Q_iQ_j}{V_iV_j}D_{ij}V_{ij}\frac{1}{\sin\theta} \quad \text{for } 10^o < |\theta| < 170^o$$

$$= \frac{3\ x\ 185}{3.09\ x\ 2.572}102.51\ x\ 1.547\ x\ \frac{1}{0.5}$$

$$= 1.86 \cdot 10^{-4}$$

- The frequency of crossing collision in 30°, λ:

  $\lambda \;= P_c \; x \; N_G$, *where P_C equals to 0.000108 base on IWRAP theory*

  $= 0.000108 \times 1.86 \cdot 10^{-4}$

  $= 2.0089 \cdot 10^{-8}$

  Total of all calculation = **0.007768**

➢ Example of calculation of crossing collision with track angle equals to 90°, there are data to analyze the collision:

Length of ship in *i* direction (L_i)	: 58	m	
Breadth of ship in *i* direction (B_i)	: 12.832m		
Length of ship in *j* direction (L_j)	: 141	m	
Breadth of ship in *j* direction (B_j)	: 23.5	m	
Total of ship in *i* direction (Q_i)	: 189	units	
Total of ship in *j* direction (Q_j)	: 109	units	
Velocity of ship in *i* direction (V_i)	: 6	kts	= 3.09 m/s
Velocity of ship in *i* direction (V_j)	: 5	kts	= 2.572 m/s
Center of ship's path way of ship *i* (μ_i)		: 0	
Center of ship's path way of ship *j* (μ_j)		: 0	
Standard deviation of ship in *i* direction (σ_i) : 75			
Standard deviation of ship in *j* direction (σ_j) : 75			
Track angles, (θ)	: 90°		
Sin θ	: 1		
Cos θ	: 0		

- Relative velocity, V_{ij}:

$$V_{ij} = \sqrt{(V_i)^2 + (V_j)^2 - 2V_iV_j cos\theta}$$

$$= \sqrt{(3.09)^2 + (2.572)^2 - 2 \; x \; 3.09 \; x \; 2.572 \; x \; 0}$$

$$= 4.02 \quad \text{m/s}$$

- Collision diameter, D_{ij}:

$$D_{ij} = \frac{L_iV_j + L_jV_i}{V_{ij}} + B_j\left\{1 - \left(\sin\theta\,\frac{V_i}{V_{ij}}\right)^2\right\}^{1/2} + \left\{B_i 1 - \left(\sin\theta\,\frac{V_i}{V_{ij}}\right)^2\right\}^{1/2}$$

$$= \frac{58x2.572 + 141x3.09}{4.02} + 23.5\left\{1 - \left(0.5\,x\,\frac{2.572}{4.02}\right)^2\right\}^{1/2} + 12.832\left\{1 - \left(0.5\,x\,\frac{3.09}{4.02}\right)^2\right\}^{1/2}$$

$$= 268.023 \quad \text{m}$$

- Numerical geometry as candidates of crossing collision, N_G:

$$N_G^{crossing} = \sum_{i.j} \frac{Q_i Q_j}{V_i V_j} D_{ij} V_{ij} \frac{1}{\sin\theta} \quad \text{for } 10^o < |\theta| < 170^o$$

$$= \frac{189 \ x \ 109}{3.09 \ x \ 2.572} 268.023 \ x \ 4.02 \frac{1}{1}$$

$$= 0.0235$$

- The frequency of crossing collision in 90^o , λ:

λ = P_c x N_G , *where P_C equals to 0.000108 base IWRAP theory*

= 0.000108 x 0.0235

= 2.53 · 10^{-6}

Total of all calculation = **0.008017**

➢ Example of calculation of crossing collision with track angle equals to 120^o, there are data to analyze the collision:

Length of ship in *i* direction (L_i)	: 32	m	
Breadth of ship in *i* direction (B_i)	: 9.44	m	
Length of ship in *j* direction (L_j)	: 90	m	
Breadth of ship in *j* direction (B_j)	: 17.544m		
Total of ship in *i* direction (Q_i)	: 240		
Total of ship in *j* direction (Q_j)	: 196		
Velocity of ship in *i* direction (V_i)	: 6	kts	= 3.09 m/s
Velocity of ship in *i* direction (V_j)	: 5	kts	= 2.572 m/s
Center of ship's pathway of ship *i* (μ_i)	: 0		
Center of ship's pathway of ship *j* (μ_j)	: 0		
Standard deviation of ship in *i* direction (σ_i)	: 75		
Standard deviation of ship in *j* direction (σ_j)	: 75		
Track angles, (θ)	: 120^o		
Sin θ	: 0.867		
Cos θ	: 0.5		

- Relative velocity, V_{ij}:

$$V_{ij} = \sqrt{(V_i)^2 + (V_j)^2 - 2V_iV_j cos\theta}$$

$$= \sqrt{(3.09)^2 + (2.572)^2 - 2 \ x \ 3.09 \ x \ 2.572 \ x \ 0.5}$$

$$= 2.864 \text{ m/s}$$

- Collision diameter, D_{ij}:

$$D_{ij} = \frac{L_i V_j + L_j V_i}{V_{ij}} + B_j \left\{ 1 - \left(\sin\theta \frac{V_i}{V_{ij}} \right)^2 \right\}^{1/2} + \left\{ B_i 1 - \left(\sin\theta \frac{V_i}{V_{ij}} \right)^2 \right\}^{1/2}$$

$$= \frac{32x2.572 + 90x3.09}{2.864} + 17.544 \left\{ 1 - \left(0.5\, x \frac{2.572}{2.864} \right)^2 \right\}^{1/2}$$

$$+ 17.544 \left\{ 1 - \left(0.5\, x \frac{3.09}{2.864} \right)^2 \right\}^{1/2}$$

$= 192.542$ m

- Numerical geometry as candidates of crossing collision, N_G:

$N_G^{crossing} = \sum_{i.j} \frac{Q_i Q_j}{V_i V_j} D_{ij} V_{ij} \frac{1}{\sin\theta}$ for $10^o < |\theta| < 170^o$

$= \frac{240\ x\ 196}{3.09\ x\ 2.572} 192.542\ x\ 2.864 \frac{1}{0.867}$

$= 0.0316$

- The frequency of crossing collision in 120°, λ:

λ $= P_c\ x\ N_G$, *where P_C equals to 0.000108 base IWRAP theory*

$= 0.000108 \text{ x } 0.0316$

$= 3.42 \cdot 10^{-6}$

Total of all calculation = **0.007826**

After performing calculations on all scenarios from crossing collision. It can be seen that the differences of angular track does not greatly affect to the result of frequency of crossing collision. For example, when the track angle equals to 30°, the result of crossing collision frequency is 0.007769. Meanwhile, for 90° angle, frequency of collision is 0.008017. This shows that the large angular difference between the two crossing collision scenarios yields almost the same frequency.

The following are the results of the frequencies calculation of the track angle 30° ; 90° ; 120° and result of frequency of IWRAP analysis:

Frequency in 30°, λ_{30^o} = 0.007768
Frequency in 90°, λ_{90^o} = 0.008017
Frequency in 120°, λ_{120^o} = 0.007826
Frequency of IWRAP analysis, = 0.007789

4.5.4 Powered Grounding

Powered grounding is kind of ship grounding caused by human error and external condition, for example ship collision. These conditions make ship in dead ship condition. Because of that, the direction of wind and wave will effect to ship. It can cause ship grounding. To analyze frequency of powered grounding in SWAC, there are required data to calculate the frequency.

Thus, frequency of powered grounding can be calculated as follow.

$$N_I = \sum_{Ship\ class,i} P_{c,i} Q_i \int_{z_{min}}^{z_{max}} f_i(z)dz$$

Where,

z_{max} = 1200 m

z_{min} = 195 m

$\int_{z_{min}}^{z_{max}} f_i(z)dz$: Probability density function for the ship traffic

$= \phi(\frac{1200-0}{300}) - \phi(-\frac{195-0}{300})$

= 0.9987 – 0.7422

= 0.2578

$P_{c,i}$: Causation probability, i.e. ratio between ship grounding and ships on a grounding course $=2.10^{-4}$

In this case, the ship that have risk to ground caused by shipwrecks is a type of oil tanker and container. The scenario is done to the oil tankers, because the oil tanker is a ship with a cargo that is harmful to the surrounding environment. If the oil tanker undergoes grounding then the fuel and cargo of the ship will pollute the sea. Meanwhile, the container is the vessel with the largest number of sailing around SWAC based on data clustering.

The number of ship = 4655 units.

Because, the shipwreck's furthest distance is three times the standard deviation, it is assumed that the number of vessels passing through the shipwrecks area is one-fourth of the vessels above. Thus, Qi = 4655/4 = 1164 units.

Thus frequency of powered grounding,

$$N_I = \sum_{Ship\ class,i} P_{c,i} Q_i \int_{z_{min}}^{z_{max}} f_i(z)dz$$

$= 2.10^{-4} \times 1164 \times 0.2578$

$= 0.0061$

Meanwhile, the frequency of powered grounding using IWRAP = 0.007764

4.5.5 Drifting Grounding

Drifting grounding is caused by engine failure and fail when anchoring. This condition will cause the ship to be carried by drift / drift so that the ship ran aground due to the existence of the shipwreck or other objects. To analyze frequency of drifting grounding, there are calculations:

Frequency of ships, Q_i = 1552 units/year = 0.177 units/h
Causation, P_C = $1.6 \cdot 10^{-4}$
Length of segment, L_W = 1000 m
Ship velocity, v_s = 10 m/s
Blackout frequency, $\lambda_{blackout}$ = $8.56 \cdot 10^{-5}$ per hour
Scale parameter, a = 1.05
Shape parameter, b = 0.9
Drift velocity, V_{drift}.
The assumption of V_{drift} equals to = 2 m/s = 5.83 kts
Length of L_W to obstacle, d_{ground} = 1000 m = 0.54 nautical mile

- Probability of blackout, $P_{blackout}$

$$P_{blackout}(L_{segment}) = 1 - exp\left(-\lambda_{blackout}\frac{L_{segment}}{v_{vessel}}\right)$$
$$= 1 - exp\left(-8.56\,.\;10^{-5}\frac{0.54}{10}\right)$$
$$= 4.62 \cdot 10^{-6}$$

- Probability of no repair, $P_{\text{no repair}}$

$$t_{\text{ground}} = \frac{d_{\text{ground}}}{v_{\text{drift}}}$$
$$= \frac{0.54}{5.83}$$
$$= 0.0925$$

$$P_{\text{no repair}}(t) = \exp(-at^b)$$
$$= \exp(-1.05 \text{ x } 0.0925^{0.9})$$
$$= 0.837$$

- Probability of no anchor $P_{\text{no anchor}}$

To determine value of $P_{\text{no anchor}}$, we have to determine Beaufort Scale first. This number is based on the wind speed around SWAC. The average of wind speed per year is 7 knot. Thus, the number of Beaufort Scale is 4. According to IALA Report No. 18591.620/TECH_DOC/2 probability of anchor equals to 0.05.

- Frequency of drifting grounding

$$N_{grounding}^{drift} = N_{ship} \int_{\psi=0}^{360} P_{wind}(\psi) \sum_{All\ segments} P_{blackout}(L_{segment}) \int_{x=0}^{L_{segment}} \int P_{no\ repair}(t_{ground} \mid Z)$$

$$P_{no\ anchoring}(t_{ground|Z)} f(v_{drift}) dv_{drift} dx d\psi$$

$$N_{grounding}^{drift} = 0.177\ x\ 4.62\ x\ 10^{-6}\ x\ 0.354\ x\ 0.05\ x\ 24\ x\ 360$$
$$N_{grounding}^{drift} = 1.27 \cdot 10^{-4}$$

Thus, the analysis of frequency of drifting grounding using IWRAP = $1.196 \cdot 10^{-4}$

4.6 Consequences Analysis

4.6.1 Consequences of ship collision

The simulation of ship collision is done by Product oil tanker and bulk carrier. The calculation is determined by Shengming Zhang in his book The Mechanics of Ship Collisions. The total dissipation energy equal to external dynamics of ship when collide. The external dynamics can be analysis as follow:

Table 8. Principle Dimension of Simulation Ships

Ship Name	Sapta Samudra	Caraka Jaya Niaga III 32	**Unit**
Ship type	Product Oil	Cargo	
Length (Lpp)	102	92	m
Width (B)	18.8	16.5	m
Height (H)	8.5	7.8	m
Draught (D)	6	5.5	m
DWT	6864	3650	ton
LWT	2516	2415	ton
GT	4725	3257	GT
Main Engine	2 x 1700	2050	KW
RPM	650	207	rpm
Service Speed	12	14	kts
Displacement	9380	6065	ton

Product oil tanker will be striking vessel and bulk carrier will be struck vessel. The added mass coefficient will be used to complete the calculation. Added mass coefficient are:

- Coefficient mass of surge motion
  $m_{ax}=m_{b1}= 0.02 – 0.07$, chosen 0.05
- Coefficient mass of sway motion
  $m_{ay}=m_{b2}=0.3 – 1.3$, chosen 1
- Coefficient mass of yaw motion
  $J_a=j_b= 0.21$
- Identification of ship condition
  - $\alpha = \beta = 30^o$
  - Forward speed of striking vessel, v_{ax} = 6 kts = 3.09 m/s
  - Sway speed of striking vessel, v_{ay} = 3 kts = 1.54 m/s
  - Forward and sway speed of struck vessel, $v_{b1} = v_{b2} = 0$ kts, anchoring condition
  - Radius of inertia moment of ship

    $R_a = \frac{L_a}{4}$
    $= 25.565$

    $R_b = \frac{L_b}{4}$
    $= 25.25$

➢ Calculating the coefficients $D_{\alpha\xi}$, $D_{\alpha\eta}$, $D_{b\xi}$, $D_{b\eta}$, $K_{\alpha\xi}$, $K_{\alpha\eta}$, $K_{b\xi}$, and $K_{b\eta}$:

- $D_{\alpha\xi} = \frac{1}{1+m_{ax}} sin^2\alpha + \frac{1}{1+m_{ay}} cos^2\alpha + \frac{4}{1+j_a} cos^2\alpha$
  $= 3.092$

- $D_{\alpha\eta} = \left(\frac{1}{1+m_{ax}} - \frac{1}{1+m_{ay}} - \frac{4}{1+j_a}\right) \sin\alpha \cos\alpha$
  $= -1.236$

- $D_{b\xi} = \frac{1}{1+m_{b2}} + \frac{16}{1+j_b} . \left(\frac{d}{L_b}\right)^2$
  $= 1.018$

- $D_{b\eta} = \frac{8}{1+j_b} . \left(\frac{B.d}{L_b{}^2}\right)$
  $= 0.243$

- $K_{\alpha\xi} = \left(\frac{1}{1+m_{ax}} - \frac{1}{1+m_{ay}} - \frac{4}{1+j_a}\right) \sin\alpha \cos\alpha$
  $= -1.236$

- $K_{\alpha\eta} = \frac{1}{1+m_{ax}} cos^2\alpha + \frac{1}{1+m_{ay}} sin^2\alpha + \frac{4}{1+j_a} sin^2\alpha$
  $= 1.451$

- $K_{b\xi} = \frac{8}{1+j_b} . \left(\frac{B.d}{{L_b}^2}\right)$
  $= 0.247$

- $K_{b\eta} = \frac{1}{1+m_{b1}} + \frac{4}{1+j_b} . \left(\frac{B}{L_b}\right)^2$
  $= 1.067$

➢ Calculating D_ξ, D_η, K_ξ, and K_η

- $D_\xi = \frac{D_{\alpha\xi}}{M_a} + \frac{D_{b\xi}}{M_b}$
  $= 4.39 \cdot 10^{-4}$
- $D_\eta = \frac{D_{\alpha\eta}}{M_a} + \frac{D_{b\eta}}{M_b}$
  $= -1.06 \cdot 10^{-4}$

- $K_\xi = \frac{K_{\alpha\xi}}{M_a} + \frac{K_{b\xi}}{M_b}$
  $= -1.06 \cdot 10^{-4}$

- $K_\eta = \frac{K_{\alpha\eta}}{M_a} + \frac{K_{b\eta}}{M_b}$
  $= 2.69 \cdot 10^{-4}$

➢ Calculating relative motion ξ and η

- $\xi = V_{ax} \sin \alpha + V_{ay} \cos \alpha - V_{b2}$
  $= 2.879$

- $\eta = V_{ax} \cos \alpha - V_{ay} \sin \alpha - V_{b1}$
  $= 1.901$

➢ Calculating energy

- $E_\xi = \frac{1}{2} . \frac{M_a / D_\xi}{1 + M_a / D_\xi . D_\eta / M_b} \xi^2$
  $= 103$ MJ
- $E_\eta = \frac{1}{2} . \frac{M_a / K_\xi}{1 + M_a / K_\xi . K_\eta / M_b} \eta^2$
  $= 40$ MJ

- Resultant Energy
  - $E_R = \sqrt{E_\xi{}^2 + E_\eta{}^2}$
    $= 110 \text{ MJ}$

4.6.2 Finite element analysis of ship collision

Ship collision model is analyzed by Ansys explicit dynamics analysis. Striking ship is expressed by midship part and struck ship expressed by forepeak part. Initial condition and assumption of condition is determined to analyze the collision.

Dimensions of model:

- Striking ship
  Length = 13 m
  Width = 6 m
  Height = 4 m
- Struck ship
  Length = 5 m
  Width = 9 m
  Height = 6 m

Initial condition:

- Velocity = 6 kts or 3 m/s
- Number of cycle = 96,000 cycles
- Density = 9.8 m/s^2

There are three solutions are used to analyze the impact of ship collision between striking and struck ship. The solutions are total deformation, directional deformation, and equivalent (von-mises) stress. Largest impact occur in equivalent stress with 1,639 Mpa. Therefore, smallest impact is 182 Mpa.

Total deformation is the sum of all vector deformation occur in ansys analysis, means the RMS of X axis, Y axis, and Z axis of directional deformation. Directional deformation itself can be determined as appear displacement of system in particular axis direction. Meanwhile, equivalent (von-mises) stress interpret stress in deformation area.

- Total Deformation

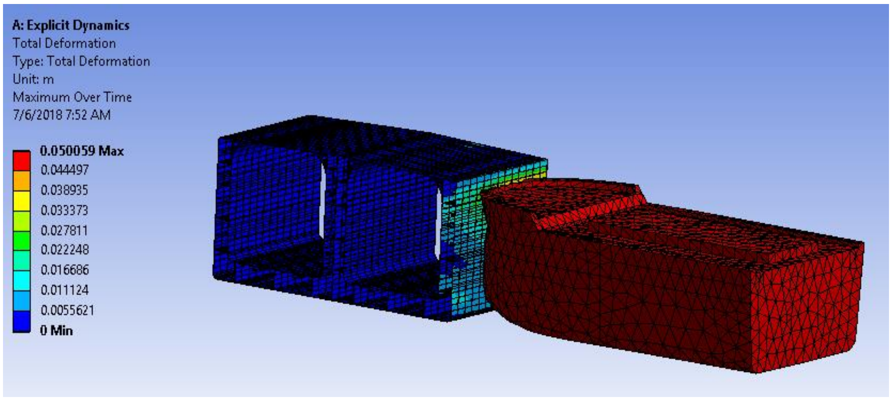

Figure 4.7 Result of Total Deformation of Ship Collision

- Maximum total deformation = 5 x 10^{-2} m
- Minimum total deformation = 5.5 x 10^{-3} m

- Equivalent stress

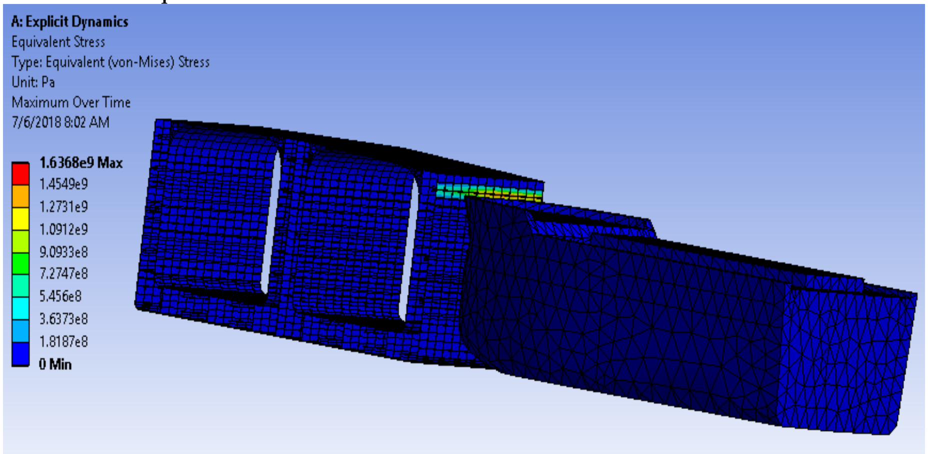

Figure 4.8 Result of Equivalent Stress of Ship Collision

- Maximum equivalent stress = 1.64 x 10^{9} Pa
- Minimum equivalent stress = 1.81 x 10^{8} Pa

4.6.3 Consequences of ship grounding

Simulation of ship grounding in this case is modeled by product oil tanker and one of the existence shipwrecks around Surabaya West Access Channel (SWAC). The analysis of ship grounding consequences can be determined by the external dynamics of ship grounding. It is can be analysis as follow theory in Mechanics of Ship Grounding by Bo Cerup Simonsen.

Consequence of grounding is modeled by:

- Grounded Ship
  - Ship name : Sapta Samudra
  - Ship type : Product Oil
  - Length (Lpp) : 102 m
  - Width (B) : 18.8 m
  - Height (H) : 8.5 m
  - DWT : 6864 ton
  - LWT : 2516 ton
  - GT : 4725 GT
  - Main engine : 2x1700 KW
  - RPM : 650 rpm
  - Service speed : 12 kts
  - Displacement : 9380 ton

- Shipwreck
  - Shipwreck name: Ex Numangguri
  - Length : 60 m
  - Width : 11,5 m
  - Height : 6,15 m
  - Condition : Tilt at starboard 45°
  - Coordinate : -7,1894 ; 122,722

According to (Simonsen, 1997) the kinetic energy can be analyzed as follow:

$$E_K = \frac{1}{2}\ x\ M\ x\ v^2$$

Where, E_K : Kinetic energy
M : Mass of grounded ship = 9380 ton
v : Velocity of grounded ship = 6 kts = 3.09

Thus the total of kinetic energy of grounded ship is:

$$E_K = \frac{1}{2}\ x\ M\ x\ v^2$$
$$= \frac{1}{2}\ x\ 9{,}38 \cdot 10^6\ x\ 3.09^2$$
$$= 44{,}5\ \text{MJ}$$

4.6.4 Finite element analysis of ship grounding

Ship grounding simulation is modelled by midship part represent the grounded ship and the forepeak part represent the shipwreck. The dimension of these models are:

- Grounded ship
  Length = 9 m
  Width = 5 m
  Height = 5.6 m

- Shipwreck
  Length = 10 m
  Width = 5 m
  Height = 3 m

Initial condition:

- Velocity = 8 kts or 4 m/s
- Number of cycle = 50000 cycles
- Density = 9.8 m/s^2

- Total Deformation

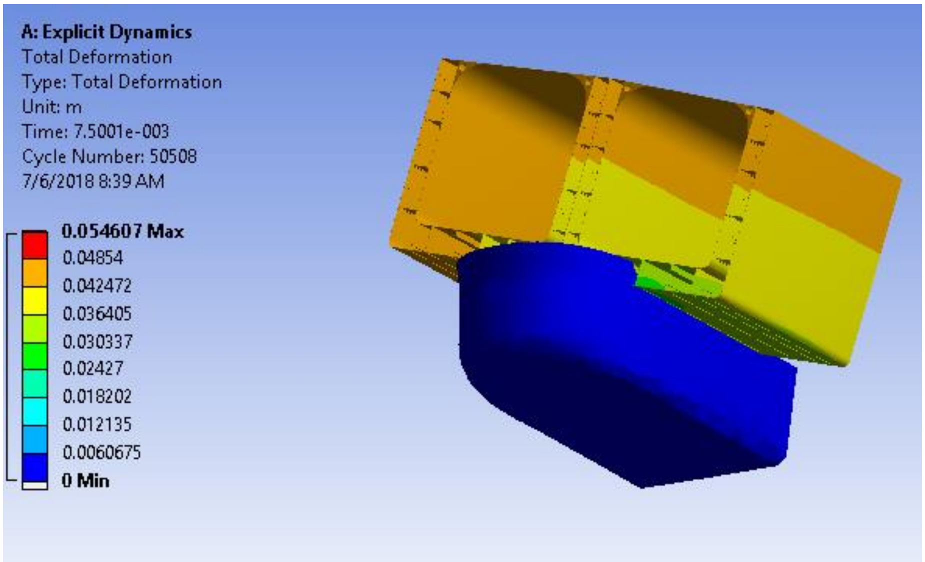

Figure 4.9 Result of Total Deformation of Ship Grounding

- Maximum total deformation = 5.4 x 10^{-2} m
- Minimum total deformation = 6.06 x 10^{-3} m

- Equivalent stress

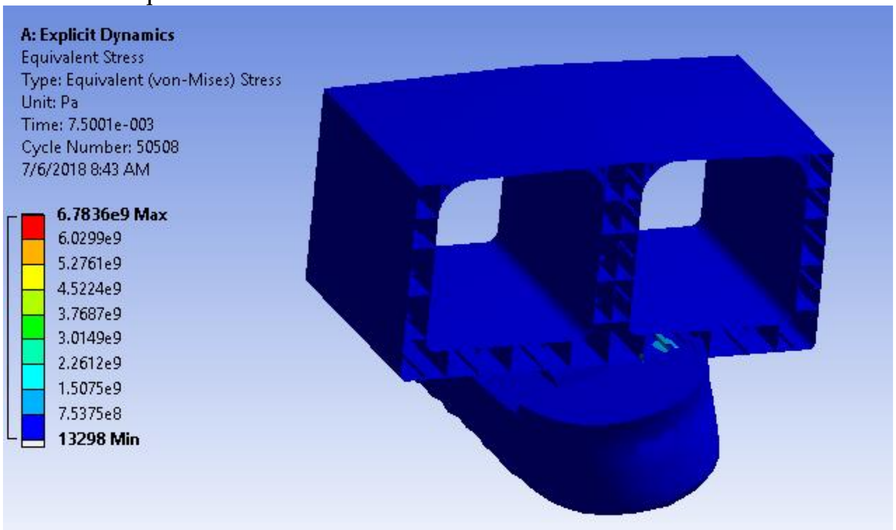

Figure 4.10 Result of Equivalent Stress of Ship Grounding

- Maximum equivalent stress = 6.78×10^9 Pa
- Minimum equivalent stress = 1.33×10^4 Pa

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CHAPTER 5
CONCLUSIONS

5.1 Conclusions

The conclusions of this risk assessment are:

1. The results of frequencies of ship collision and grounding scenarios are:
   - Head-on collision
     Manual = $6.99 \cdot 10^{-3}$
     IWRAP = $7.07 \cdot 10^{-3}$

   - Overtaking collision
     Manual = $1.02 \cdot 10^{-3}$
     IWRAP = $9.04 \cdot 10^{-4}$

   - Crossing collision 30^o
     Manual = $7.768 \cdot 10^{-3}$
     IWRAP = $7.789 \cdot 10^{-3}$

   - Powered grounding
     Manual = $6.1 \cdot 10^{-3}$
     IWRAP = $7.764 \cdot 10^{-3}$

   - Drifting grounding
     Manual = $1.27 \cdot 10^{-4}$
     IWRAP = $1.196 \cdot 10^{-4}$

2. The analysis of ship collision produce the dissipation energy of ship collision equals to 110 MJ and the dissipation energy of ship grounding is 44.5 MJ.

3. The value of total deformation of ship collision and ship grounding using Ansys are:
   - Ship collision:
   Maximum total deformation = 5×10^{-2} m
   Minimum total deformation = 5.5×10^{-3} m
   - Ship grounding:
   Maximum total deformation = 5.4×10^{-2} m
   Minimum total deformation = 6.06×10^{-3} m

4. The value of equivaleny stress of ship collision and ship grounding using Ansys are:
   - Ship collision:

   Maximum equivalent stress = 1.64×10^9 Pa
   Minimum equivalent stress = 1.81×10^8 Pa

   - Ship grounding:

   Maximum equivalent stress = 6.78×10^9 Pa
   Minimum equivalent stress = 1.33×10^4 Pa

5.2 Suggestion

The consequences analysis of Ansys program have not considered the direction of sea wave. It is important to analysis the ship accident when ship has anchored.

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APPENDIX

Calculation of energy dissipation of ship collision:

- Calculating the coefficients $D_{\alpha\xi}$, $D_{\alpha\eta}$, $D_{b\xi}$, $D_{b\eta}$, $K_{\alpha\xi}$, $K_{\alpha\eta}$, $K_{b\xi}$, and $K_{b\eta}$:

- $$D_{\alpha\xi} = \frac{1}{1+m_{ax}} sin^2\alpha + \frac{1}{1+m_{ay}} cos^2\alpha + \frac{4}{1+j_a} cos^2\alpha$$
$$= \frac{1}{1+0.55} 0.025 + \frac{1}{1+1} 0.74 + \frac{4}{1+0.21} 0.74$$
$$= 3.092$$

- $$D_{\alpha\eta} = \left(\frac{1}{1+m_{ax}} - \frac{1}{1+m_{ay}} - \frac{4}{1+j_a}\right) \sin\alpha \cos\alpha$$
$$= -1.236$$

- $$D_{b\xi} = \frac{1}{1+m_{b2}} + \frac{16}{1+j_b} . \left(\frac{d}{L_b}\right)^2$$
$$= 1.018$$

- $$D_{b\eta} = \frac{8}{1+j_b} . \left(\frac{B.d}{{L_b}^2}\right)$$
$$= 0.243$$

- $$K_{\alpha\xi} = \left(\frac{1}{1+m_{ax}} - \frac{1}{1+m_{ay}} - \frac{4}{1+j_a}\right) \sin\alpha \cos\alpha$$
$$= -1.236$$

- $$K_{\alpha\eta} = \frac{1}{1+m_{ax}} cos^2\alpha + \frac{1}{1+m_{ay}} sin^2\alpha + \frac{4}{1+j_a} sin^2\alpha$$
$$= 1.451$$

- $$K_{b\xi} = \frac{8}{1+j_b} . \left(\frac{B.d}{{L_b}^2}\right)$$
$$= 0.247$$

- $$K_{b\eta} = \frac{1}{1+m_{b1}} + \frac{4}{1+j_b} . \left(\frac{B}{L_b}\right)^2$$
$$= 1.067$$

- Calculating D_ξ, D_η, K_ξ, and K_η
  - $D_\xi = \frac{D_{\alpha\xi}}{M_a} + \frac{D_{b\xi}}{M_b}$
    $= 4.39 \cdot 10^{-4}$
  - $D_\eta = \frac{D_{\alpha\eta}}{M_a} + \frac{D_{b\eta}}{M_b}$
    $= -1.06 \cdot 10^{-4}$
  - $K_\xi = \frac{K_{\alpha\xi}}{M_a} + \frac{K_{b\xi}}{M_b}$
    $= -1.06 \cdot 10^{-4}$
  - $K_\eta = \frac{K_{\alpha\eta}}{M_a} + \frac{K_{b\eta}}{M_b}$
    $= 2.69 \cdot 10^{-4}$
- Calculating relative motion ξ and η
  - $\xi = V_{ax} \sin\alpha + V_{ay} \cos\alpha - V_{b2}$
    $= 2.879$
  - $\eta = V_{ax} \cos\alpha - V_{ay} \sin\alpha - V_{b1}$
    $= 1.901$
- Calculating energy
  - $E_\xi = \frac{1}{2} \cdot \frac{M_a/D_\xi}{1 + M_a/D_\xi \cdot D_\eta/M_b} \xi^2$
    $= 103$ MJ
  - $E_\eta = \frac{1}{2} \cdot \frac{M_a/K_\xi}{1 + M_a/K_\xi \cdot K_\eta/M_b} \eta^2$
    $= 40$ MJ
- Resultant Energy
  - $E_R = \sqrt{{E_\xi}^2 + {E_\eta}^2}$
    $= 110$ MJ

Calculation of energy dissipation of ship grounding:

$$E_K = \frac{1}{2}\ x\ M\ x\ v^2$$

Where, E_K : Kinetic energy

M : Mass of grounded ship = 9380 ton

v : Velocity of grounded ship = 6 kts =

Thus the total of kinetic energy of grounded ship is:

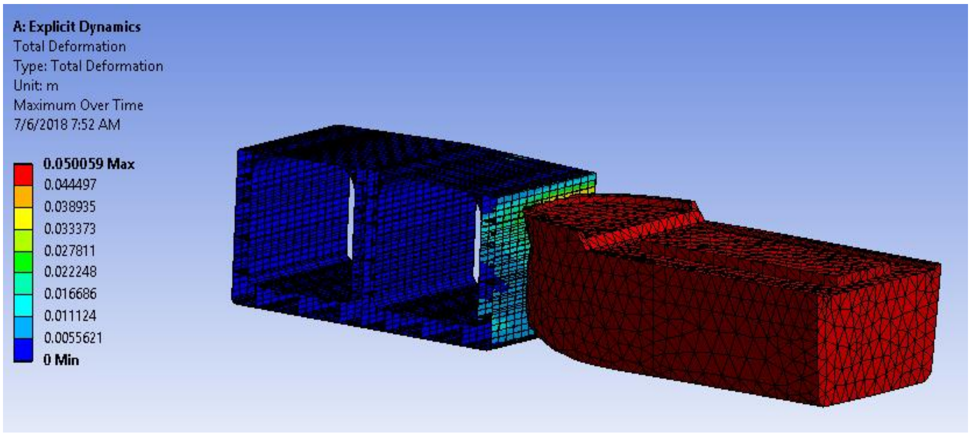
$$E_K = \frac{1}{2}\ x\ M\ x\ v^2$$

$$= \frac{1}{2}\ x\ 9{,}38 \cdot 10^6\ x\ 3.09^2$$

$$= 44{,}5\ \text{MJ}$$

Results of consequences of ship collision

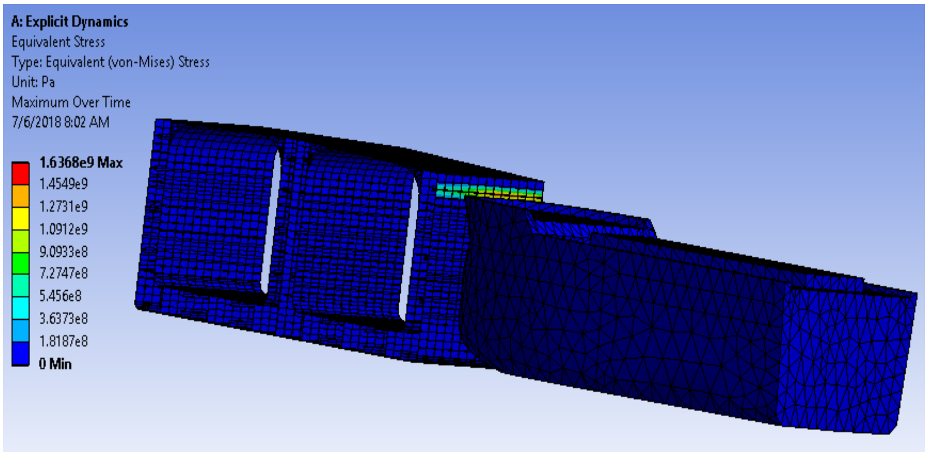
- Total Deformation



Maximum total deformation = 5 x 10^{-2} m

Minimum total deformation = 5.5 x 10^{-3} m

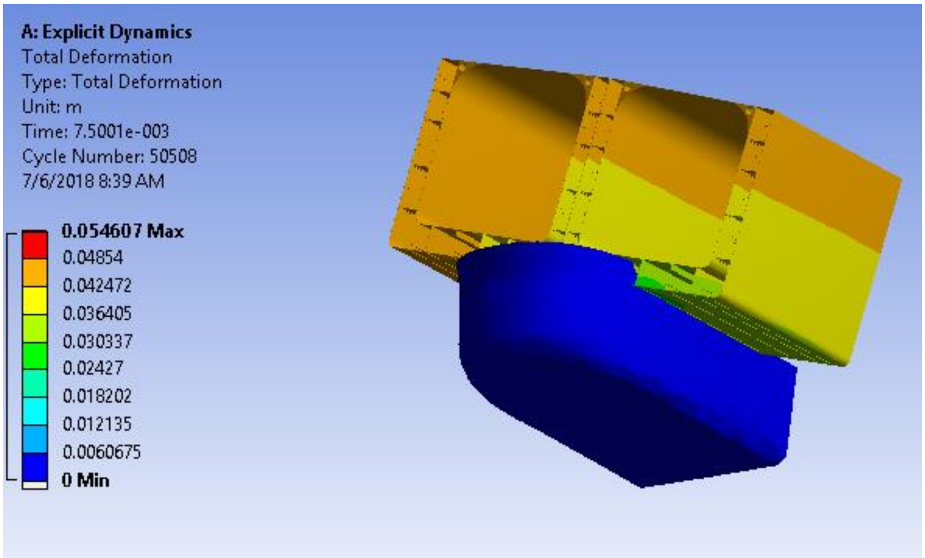
- Equivalent stress



Maximum equivalent stress = 1.64×10^{9} Pa
Minimum equivalent stress = 1.81×10^{8} Pa

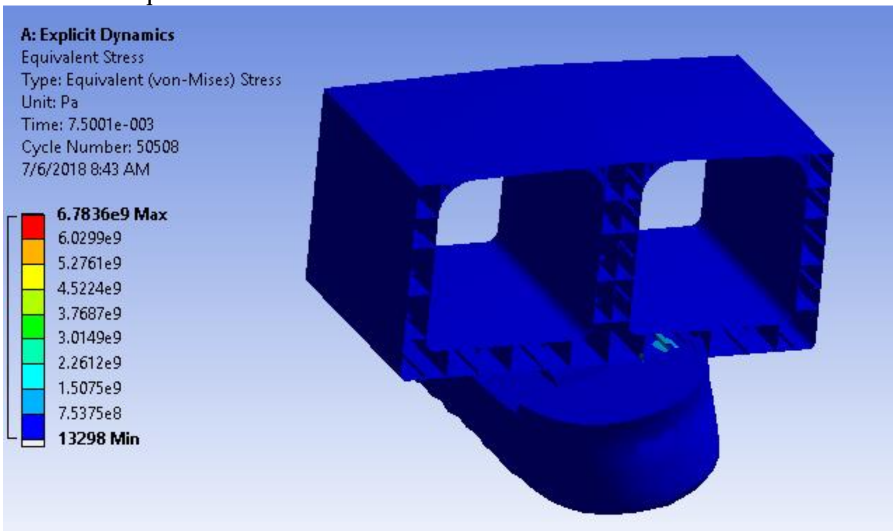
Results of consequences of ship collision

- Total Deformation



Maximum total deformation = 5.4×10^{-2} m
Minimum total deformation = 6.06×10^{-3} m

- Equivalent stress



Maximum equivalent stress = 6.78×10^{9} Pa
Minimum equivalent stress = 1.33×10^{-4}

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The author was born on July 25th, 1996 with the full name Joko Sutrisno. The author was the youngest brother from three children from the couple of Mr. Sudarminto and Mrs. Kustiwi. The author began his studies in kinderganden of TK Darma Wanita to SDN Sukomoro III graduated then SMPN 2 Nganjuk, graduated on 2011. Then continued his education to SMAN 2 Nganjuk until 2014. After graduated from senior high school, the author continued to the Department of Marine Engineering, Faculty of Marine Technology, ITS Surabaya at 2014 with student number 04211441000011. He took the bachelor thesis on Laboratory of Reliability, Availability, Management, and Safety (RAMS). With the title Risk Assessment of Ship Collision and Grounding in Surabaya West Access Channel due to the Existence of Shipwrecks.